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OF THE

AMERICAN PHYSICAL SOCIETY

INCLUDING THE
PROGRAMME OF THE

1957 WASHINGTON MEETING

AT

WASHINGTON, D. C.

April 25, 26, and 27

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George Braxton Pegram

Treasurer Emeritus of the American Physical Society

Treasurer, 1919–1957

THIS 1957 Annual Meeting is the last meeting at which George Braxton Pegram is the Treasurer of the American Physical Society. This Society as we know it is largely his own creation. When he entered the Society fifty-eight years ago at its second meeting, it had fewer than one hundred members. When he was first elected Treasurer thirty-eight years ago, the Society was still less than one-tenth as large as it is today. The volume of its publications was an even smaller fraction of their present volume, and nobody could have dared to say that our *Physical Review* is the most important journal of physics in the world, a claim that now might not appear unreasonable. Its meetings were so small that simultaneous sessions were unknown; now there are six or seven at a time. For all of these thirty-eight years George Pegram has served the Society without a break, by far the longest term of service ever accorded to us by anyone. Years of prosperity and depression, years of deflation and inflation, and now a decade of unremitting expansion of physics and of the Society—through all this time George Pegram has maintained the finances of the Society, and only twice in all this time have the vicissitudes of the years required an appeal for brief and transient help to surmount a temporary crisis. When Pegram began to be Treasurer, he was at an age when most men are working full time in their own profession, and he himself, according to all that we hear, was working half again as hard as most men. He has continued to be Treasurer up to an age when most men want nothing but rest and ease and when his own physician has long been urging him to relax and quit. And yet, immense as has been his service as Treasurer, it is but a small part of his total service. For longer than most of us can remember George Pegram has been the guide and the elder statesman of the Society, always concerning himself with everything that concerned the Society, always foresighted, and always vigilant. Those who will be officers hereafter will feel like children who have lost the guidance of the wise and kindly father on whom they have always relied to lead them, to advise them, to keep them out of trouble, and to help them out of such troubles as they incurred on their own. Of course, we count on the continuance of his good counsel. The American Physical Society will never be able to measure what it owes to George Braxton Pegram. He has been the Society incarnate. There will never be another like him.

The foregoing statement, prepared at the direction of the Council of the American Physical Society, was read at the banquet of February first, 1957.

April 25, 1957 Series II, Vol. 2, No. 4

BULLETIN

OF THE

AMERICAN PHYSICAL SOCIETY

1957 Washington Meeting, April 25, 26, and 27, 1957

THE **1957 Spring Meeting of the American Physical Society** will be held in Washington, D. C., on Thursday, Friday, and Saturday, **April 25, 26, and 27.** The scientific sessions will be distributed, as they were last year, between the Sheraton-Park Hotel, the Shoreham Hotel, and the National Bureau of Standards. The meeting, as measured by number of papers contributed and invited, is of about the same proportion as last year's: whether the future reserves for us such an amazing and troublesome gain in attendance as surprised us at the latest Annual Meeting is something that remains for the future to tell. R. D. Huntoon has accepted for the third time the tremendous burdens of the Chairmanship of the Local Committee: his committeemen are D. F. Bleil, W. C. Hall, A. I. Mahan, J. H. McMillen, S. F. Singer, L. Slack, and H. Tatel—it will be seen that the major institutions of Washington have given generously of their aid.

Last-minute correspondence to officers of the Society, to chairmen of sessions, and to members generally should be addressed in care of R. D. Huntoon, Room 106-108C, Sheraton-Park Hotel, Washington 8, D. C.

Hotel. Room reservations should be made by writing to the Sheraton-Park Hotel, Washington 8, D. C., with mention that the writer is coming to the convention of the American Physical Society. Late writers will find themselves assigned to other hotels, probably in the same neighborhood. Even with the best will in the world, a hotel cannot always fulfill a confirmed reservation when the maker thereof does not arrive until late in the day. Get there as early as possible, and if not "roomed" at once, go back from time to time instead of waiting till evening. A deposit made in advance is often helpful.

The **main registration desk** will be located in the Sheraton-Park Hotel and an **ancillary desk** in the Shoreham. You may register at either, and everyone should register and pay the registration fee of one dollar. Dinner tickets may be bought at either. The blackboards with notices of messages, post-deadline papers, and other information will be found only at the Sheraton-Park.

Parity. The issue of nonconservation of parity—strangely miscalled "violation of parity" by a number of people who probably would not speak of an irreversible process as a "violation of entropy"—attracted an enormous crowd at the Annual Meeting even though it was on the post-deadline programme. Anticipating a similar crush, we have booked for a Symposium on this issue the Sheraton Hall, which incidentally will advantage other papers at other times. This Symposium will be held on Friday afternoon and will begin at 1:15 (!!) for we must vacate the hall at 4:30. Speakers will be T. D. Lee, C. S. Wu, R. L. Garwin, V. L. Telegdi, and K. L. Crowe. Theoretical papers on parity are assigned to the West Ballroom of the Shoreham on Thursday afternoon, and such experimental papers as could be recognized as having pertinence to the issue form a programme on Friday morning in the Main Ballroom of the Shoreham.

Two of our most recent **Nobel laureates,** John Bardeen and W. H. Brattain, will give addresses before the Society on Saturday morning in the Main Ballroom of the Shoreham (Session SA).

Invited papers by Aage Bohr, Hugh Bradner, E. S. Dayhoff, E. V. Hayward, R. Jastrow, G. R. Keepin, H. W. Lewis, W. F. Libby, P. B. Moon, E. Opik, Peter Hillman, M. M. Shapiro, J. A. Simpson, S. F. Singer, C. H. Townes, and E. H. Winkler appear in various sessions of the meeting.

Four hundred and eight contributed papers are distributed among thirty-five sessions. Last year the number was 394, the previous year 393, and the year before that 406. Papers in theoretical physics were so numerous that some of them had to be scheduled on every half-day but that of the parity symposium, and papers on transmutation and on neutron physics so abundant that some had to be put in parallel even with that. As usual, the topics assigned to Saturday afternoon are not those that were so placed at the previous Annual Meeting or the previous Washington meeting, though post-deadline papers may provide an exception. The Society and the Secretary owe a great debt to Robert Serber for arranging the theoretical papers; to W. W. Havens, the Deputy Secretary, for arranging the six sessions lettered D, E, K, P, S, and X; and to L. M. Lederman for doing the same service to those on hyperons and heavy mesons. (Incidentally, 185 of the 408 abstracts arrived on dead-

line-day. A dangerous risk; and there were nearly thirty that took the risk and lost the gamble.)

There will be *no* **placement register** at this meeting.

As at the past four meetings, there will be an exhibit of the latest technical books and journals in the Florentine Foyer to Sheraton Hall on Thursday and Friday, 9:00 A.M. to 4:30 P.M. All are cordially invited.

The **banquet of the Society** will be held on Friday evening at 7:00 in the Terrace Room of the Shoreham Hotel. The after-dinner speakers will be announced on the blackboards if their names are not to be found in this Bulletin. The Terrace Room is the one in which we have nearly always dined at Washington in recent years. Use the form on page 253 of this Bulletin for advance reservations. If you do not use it, watch vigilantly for announcement on the blackboards giving the day and hour after which tickets may no longer be available. The price of the dinner will be four dollars.

Tea. The staff of the National Bureau of Standards will be host to the Society at tea, which they will offer to the members and guests of the Society at the Manse (on the Bureau grounds) from 4:30 P.M. to 6:30 P.M. on Thursday.

The **ladies' programme** has been arranged by Mrs. Francis M. Defandorf. There will be an opportunity, for those interested, to attend a short talk in the newly completed Mosque by Dr. Mohamed Bisar, Director of the Islamic Center, on Thursday, April 25, at 1:00 P.M. In addition, arrangements have been made for a short tour of the National Cathedral. Transportation will be provided and those interested should so notify the ladies' registration desk by 11:30 A.M. on Thursday.

On Friday, April 26, the wives of the local members will provide transportation for a tour of either Mt. Vernon or a general view of Washington including Old Georgetown and parts of residential areas. Upon completion of the tour, each group will be driven directly to the Columbia Country Club in Chevy Chase, Maryland, for luncheon ($2.25). The selection of the tour desired must be announced at the time the luncheon tickets are purchased at the ladies' registration desk; the deadline is 5:00 P.M. Thursday, April 25.

Also on Friday, April 26, there can be a tour of the studios of "Voice of America" (the international broadcasting service of the United States Information Service) at 1:00 P.M. if sufficiently many of our members and guests notify the ladies' registration desk before 4:45 P.M. on Thursday afternoon that they will go.

The **Council of the American Physical Society** will meet on Wednesday, April 24, at 10:30 A.M. in a place of which notification will be made to its members.

The **Nominating Committee** of the American Physical Society will meet on Thursday at 10:00 A.M. at a place of which its members will be notified. The members of this Committee are: J. H. Van Vleck (*Chairman*), J. L. Fowler, S. A. Goudsmit, Thomas Lauritsen, W. James Lyons, K. G. McKay, J. R. Platt, E. M. Purcell, and R. R. Wilson.

Post-deadline ten-minute papers, pertaining to very recent achievements of very special importance, will be considered for admission to a special supplementary programme if the abstracts are received at the office of the Society not later than Friday, April 19. The abstracts will not be published. The titles of such papers as may be accepted will be written on a blackboard near the registration desk, and on this blackboard will also be announced the time and place at which these may be given.

Prospective meetings and deadlines of the Society are listed on page 247 of this Bulletin.

Instructions for the preparation of abstracts are printed on page 247 of this Bulletin. Members should make a point of reading these instructions whenever an issue of the Bulletin appears, for they become more numerous and more rigid as the months and years pass by. This is because most of them are designed to shorten the period which the text of the Bulletin must spend in the hands of the editors at the American Institute of Physics before it goes onward to Lancaster Press, and with our present big meetings this period is getting to be a significant part of the time that elapses from the deadline to the publication of the Bulletin. Read and heed!

Errata pertaining to abstracts in this issue will be published in a later issue of this Bulletin if received not later than Monday, April 29, by Miss Ruth Bryans, American Institute of Physics, 57 East 55th Street, New York 22, New York. Do not send in the abstracts marked with corrections. Write out the corrections in the form "Instead of . . . read. . . ." Add nothing. The privilege of printing an erratum is not accorded in order to enable people to publish new data or to replace material cut out because the abstract was too long.

KARL K. DARROW, *Secretary*
American Physical Society
Columbia University
New York 27, New York

EPITOME OF THE 1957 WASHINGTON MEETING

(Personal names are those of invited speakers. NBS stands for National Bureau of Standards, SP for Sheraton-Park.)

Thursday Morning

10:00	A.	Solid-state physics I, mostly semiconductors. NBS East.
10:00	B.	Electrons and positrons; Hayward, Moon. Shoreham, Main.
10:00	C.	Instrumentation, mostly nuclear. SP, Burgundy.
10:00	CA.	Theoretical physics I: high-energy physics. SP, Caribar-Mural.
10:00	D.	Interactions of medium-weight nuclei. SP, Continental.
10:00	DA.	Opik, Singer, Shapiro, Simpson. SP, Sheraton Hall.

Thursday Afternoon

2:00	E.	Interactions of light nuclei. SP, Continental.
2:00	F.	Cryogenics; Lutes. SP, Caribar-Mural.
2:00	FA.	Solid-state physics II, mostly nonmetals. NBS, East.
2:00	G.	Accelerators. SP, Burgundy.
2:00	GA.	Theoretical physics II: field-theory and symmetry properties. Shoreham, West.
2:00	H.	Cosmic rays; antiprotons, antineutrons. Shoreham, Main.
1:45	HA.	Keepin, Hillman, Jastrow, Lewis. SP, Sheraton Hall.

Friday Morning

9:30	J.	Muons and pions. SP, Burgundy.
9:30	K.	Fission and fissile nuclei. SP, Continental.
9:30	KA.	Optical and x-ray spectra: molecular-beam experiments. SP, Caribar-Mural.
9:30	L.	Solid-state physics III, mostly theory. NBS, East.
9:30	LA.	Theoretical physics III: statistical problems. Shoreham, West.
9:30	M.	Experimental papers with a bearing on parity. Shoreham, Main.
9:30	MA.	Libby, Bohr, Bradner. SP, Sheraton Hall.

Friday Afternoon

1:15	N.	Lee, Wu, Garwin, Telegdi, Crowe. SP, Sheraton Hall.
2:00	P.	Coulomb excitation: interactions involving deuterons and alpha particles. SP, Continental.
2:00	Q.	General physics. SP, Burgundy.
2:00	QA	Microwaves and bands. Shoreham, Main.
2:00	R.	Solid-state physics IV, mostly metals. NBS, East.
2:00	RA.	Fluid dynamics; Winkler. Shoreham, West.
2:00	S.	Neutron spectroscopy. SP, Caribar-Mural.

Friday Evening

7:00 Banquet of American Physical Society. Speakers to be announced.

Saturday Morning

9:00	SA.	Ferroelectrics and dielectrics; Bardeen, Brattain, Townes. Shoreham, Main.
9:30	T.	Heavy mesons and hyperons I. Shoreham, West.
9:30	TA.	Atomic masses; general nuclear physics. SP, Continental.
9:30	U.	Magnetic resonance; Dayhoff. NBS, East.
9:30	UA.	Theoretical physics IV: low-energy physics. SP, Caribar-Mural.
9:30	V.	Unstable nuclei I. SP, Burgundy Room.

Saturday Afternoon

1:30	W.	Unstable nuclei II. SP, Burgandy.
1:30	X.	Fast neutron reactions. SP, Continental.
1:30	XA.	Post-deadline papers perhaps in West Ballroom but consult blackboard.
1:30	Y.	Heavy mesons and hyperons II. Shoreham, Main.
1:30	Z.	Magnetism. NBS, East.
1:30	ZA.	Theoretical physics V: relativity and quantum mechanics. SP, Caribar-Mural.

PROGRAMME

THURSDAY MORNING AT 10:00

NBS, East Building

(E. BURSTEIN presiding)

Solid-State Physics I, Mostly Semiconductors

A1. General Theory of the Hall Effect. P. J. PRICE, *IBM, Watson Laboratory.*—Existing theories of the Hall effect make simplifying assumptions about the relaxation processes in the Boltzmann equation. Such assumptions can be avoided by a general procedure[1] in which the magnitude averaged in the flux is replaced by a "conjugate" magnitude which is related to it by a certain integral equation. When the flux is electron current, the procedure replaces electron velocity by its conjugate: the relation between these generalizes the Lorentz correction for persistence of velocity. In this paper the method is applied to the linear Hall effect in a single crystal. The resulting formula for the conductivity triadic, in terms of the conjugate to the velocity, reduces for cubic symmetry to a formula for the Hall mobility which generalizes existing ones. The possible simplifying assumptions will be discussed.

[1] P. J. Price, IBM J. Research and Development **1**, No. 2 (April, 1957).

A2. Theory of Noise for a Multidimensional Semiconductor. M. SOLOW, *Catholic University of America and the Naval Ordnance Laboratory.*—This paper gives the solution for two- and three-dimensional $p-n$ junction noise problems, including the effects of surface recombination. The noise sources are derived by the method of Petritz.[1] The recombination sources are scalar; the bulk diffusion sources are vector in character. The noise sources are substituted into the equations of motion for excess minority charge and diffusion currents. To solve these inhomogeneous equations, the scalar and tensor Green's functions are investigated for the semi-infinite rectangular parallelopiped. The scalar Green's function is found for arbitrary values of surface recombination velocity and the tensor Green's function for the limiting case of infinite surface recombination velocity. The spectrum of the noise current appearing at the $p-n$ junction is obtained by integration of the scalar and tensor Green's functions over the recombination and diffusion sources, respectively.

[1] R. L. Petritz, Proc. Inst. Radio Engrs. **40**, 1440 (1952); Phys. Rev. **87**, 535 (1952); *ibid*, **87**, 189(A) (1952).

A3. High-Frequency Relaxation Processes in the Field-Effect Experiment. C. G. B. GARRETT, *Bell Telephone Laboratories.*—A theoretical treatment is given of two dispersion phenomena in the field-effect experiment: (1) dispersion arising from the finite time required to generate minority carriers, and (2) relaxation of the fast surface states. It is shown that the in-phase part of the field effect mobility is given by (for n-type semiconductor) $\mu_{FE}=-\mu_0+A/(1+\omega^2\tau_1^2)-B/(1+\omega^2\tau_2^2)$, where $(\omega/2\pi)$ is the frequency of the applied field, A and B are constants, and τ_1 and τ_2 are characteristic times, all four quantities being functions of the body resistivity, surface potential, and of the densities, energy levels, and capture cross sections of the fast states. Under certain conditions, τ_1 is equal to the fundamental decay mode lifetime of the sample, while τ_2 is expected to be much shorter and depends primarily on the cross sections and the position of the state level in the gap. A comparison of the theory with recent experimental results of Montgomery shows (1) that reasonable agreement can be obtained and (2) that the presence of any significant number of states in the region close to the center of the gap is unlikely.

A4. Cyclotron Resonance in Germanium. R. R. GOODMAN, *University of Michigan.*—Cyclotron resonance line shape calculations have been made for transitions between several energy levels for holes in germanium. The calculations were made for the magnetic field in the (111) direction. The occupation of the various levels was assumed given by the equilibrium distribution at a definite temperature. A comparison was made with the results of calculations in which the (111) component of momentum is taken equal to zero. The comparison showed that for some transitions the peaks of the resonance lines were within 1% of each other, although the shapes of the curves differ somewhat. For some transitions, however (those which are forbidden when the (111) component of the momentum is taken as zero), the position and shape of the line is very temperature-dependent. Their intensities are less than those of the other type of transitions. A theory using a single relaxation time τ was used and $(\omega\tau)^2$ was taken equal to 57. Temperatures of 1°K and 3°K were considered. For the sake of convenience in estimating the size of these effects, the values of the dimensionless constants

A5. Time Constants of Slow States in Germanium Surfaces. G. C. DOUSMANIS AND E. O. JOHNSON, *RCA Laboratories.*—The effect of ac electric fields on the surface recombination velocity (s) in Ge and Si diodes,[1] as detected by changes in the reverse saturation current, provides a convenient means of exploring the time constants and other properties of the slow surface states. The amplitude of the effect on s is measured as a function of applied field frequency. The response of the surface in Ge is small at frequencies less than 0.1 cps and increases with increasing frequency up to about 80 cps where a plateau region is reached. The reciprocals of these numbers determine, approximately, the range of the distribution of effective time constants for the slow states. The preceding figures apply to surfaces in a room air atmosphere. The time constants are shorter in a wet air and longer in a dry O_2 atmosphere. This is confirmed by surface photovoltage measurements.[2] High ac fields induce a net charge in the slow states, whose behavior may indicate field-induced shortening of their time constants. The surface behavior at higher frequencies will be discussed.

[1] G. C. Dousmanis, Bull. Am. Phys. Soc. Ser. II, **2**, 65 (1957).
[2] E. O. Johnson, Bull. Am. Phys. Soc. Ser. II, **2**, 66 (1957).

A6. Role of Magnetic Field in the Hot Electron Behavior of Germanium.* LOUIS GOLD, *Lincoln Laboratory.*—The hot electron problem in many-valley semiconductors has been investigated in an earlier study based upon the individual ellipsoidal energy surface model (appropriate in the regime $T\rightarrow 0$) and the anisotropy characterized for silicon and germanium.[1] The theory is now extended to the circumstance where an external magnetic field $\mathbf{H}$ is applied in germanium crystals. A simple approach is possible, ignoring collisional effects, which allows delineation of the trajectory behavior; directional energy gain is evaluated for $\mathbf{E}_{100}$ and $\mathbf{E}_{110}$ with $\mathbf{H}$ rotated in longitudinal and transverse orientations. The anisotropy is found to be quite marked (decidedly stronger than for $\mathbf{H}=0$) with the longitudinal arrangement more effective than the transverse case. The introduction of scattering considerably complicates the analysis, and consideration is

given here to the effective ratio b of Larmor to scattering frequency. In the limit $b \to \infty$ and the scattering decidedly anisotropic, transverse energy gain vanishes, whereas in the longitudinal alignment the energy gain becomes extremely anisotropic. As $b \to 0$, the anisotropy diminishes; detailed calculations have been performed for $b = 1, 0.1$ for both isotropic and anisotropic scattering.

* The research reported in this document was supported jointly by the Army, Navy, and Air Force under contract with MIT.
[1] L. Gold, Phys. Rev. **104**, 1580 (1956).

A7. Activation Energy for the Thermal Generation of Recombination Centers in Silicon. BERND ROSS AND J. R. MADIGAN, *Hoffman Semiconductor Division.*—The effect of various heat treatments (e.g., annealing, quenching, and reannealing) on silicon diffused $p-n$ junction rectifiers has been found to alter the number but not the energy level of the recombination centers.[1] This suggests that a semilogarithmic plot of lifetime *vs* reciprocal quench temperature should yield a straight line whose slope is a measure of the activation energy for formation of the recombination centers. A value of about 1 ev is thus obtained. Room temperature annealing was observed after quenching. Possible models for the recombination center and its method of generation are discussed.

[1] B. Ross and J. R. Madigan, Bull. Am. Phys. Soc. Ser. II, **2**, 65 (1957).

A8. Observations on the Spectral Dependence of the PME Effect. FRANK A. BRAND, ANDREW N. BAKER,* AND HERBERT METIE, *Signal Corps Engineering Laboratories.*—The photomagnetoelectric effect has been studied in germanium as a function of the wavelength of incident radiation in the region from 0.5 to 2.0 micron. The dependence of both photoconductivity and PME response has been measured in various samples, using front and back surface recombination velocities and bulk recombination as parameters. It has been found that under certain conditions of bulk and surface recombination a reversal in sign for the PME response occurs over the frequency range studied. Sign reversals obtain at wavelengths in the range from 1.55 to 1.85 microns, corresponding to partial optical transparency. The exact frequencies at which reversal occurs depend on the surface and bulk recombination values, the condition being that the Dember field be zero corresponding to equal carrier concentrations on the front and back surfaces. Furthermore, the present observations are shown to be in good agreement with the theoretical work reported by Gärtner.[1] Experimental procedures are described, and it is shown how this effect can be used to advantage in the study of surface recombination velocities in various environments.

* Present address at Bell Telephone Laboratories.
[1] W. Gärtner, Phys. Rev. **105**, 823 (1957).

A9. Magneto Photorectification Effect in a Semiconductor. G. GROETZINGER, *RIAS,* AND H. K. FORSTER, *University of California, Los Angeles.*—It has been observed previously that an absorption gradient of light in a transparent semiconductor leads to a (volume) rectification.[1] In the present experiment it has been found that, just as the photo-emf associated with such a gradient is diminished by the application of a transverse magnetic field (longitudinal photomagnetoelectric effect[2]), the rectification is decreased by the application of such a magnetic field. For a natural cuprous oxide crystal the rectification, as measured by the dc current produced by an ac voltage of a few volts, is decreased by 5% upon application of a field of 22 000 gauss. No rectification could be detected associated with the emf as a result of the transverse photomagnetoelectric effect (PEM effect)[3] i.e., in the direction perpendicular to both the gradient of light and the magnetic field.

[1] G. Groetzinger and J. Lichtschein, Physik. Z. **38**, 292 (1937); N. Pentz and J. Aron, Bull. Am. Phys. Soc. Ser. II, **1**, 293 (1956).
[2] G. Groetzinger, Physik. Z. **36**, 169 (1935); *ibid.* **36**, 216 (1935); J. Aron and G. Groetzinger, Phys. Rev. **100**, 1128 (1955).
[3] I. K. Kikoin and N. Noskov, Physik. Z. Sovietunion **5**, 586 (1934); G. Groetzinger, Physik. Z. **36**, 169 (1935).

A10. Rectification and Photovoltaic Effect in Semiconducting Diamond.* M. D. BELL† AND W. J. LEIVO, *Oklahoma A. and M. College.*—Rectification effects between metal points and Type IIb[1] diamonds have been studied under various conditions. Rectification was observed with each of the metals tested which included indium, aluminum, copper, tungsten, silver, and platinum. The current-voltage characteristics were in qualitative agreement with rectification theory; however, there was no quantitative agreement because the reverse saturation current was not dependent upon the work function of the metal to the extent required by theory. The lack of dependence of rectification with the work function can be explained by Bardeen's theory of surface states. Reverse breakdown occurred between 30 and 60 volts, and a luminescence was observed with 45 volts forward bias. Good rectification curves were still obtained at 300°C, the maximum temperature employed. The diamond developed photovoltages in the visible and near infrared extending from 330 mμ to 1.3 μ with the maximum at 660 mμ. In the ultraviolet the photovoltage peaked at 230 mμ.

* This research was supported by the U. S. Air Force through the Air Force Office of Scientific Research of the Air Research and Development Command.
† Now with Phillips Petroleum Company.
[1] Type IIb diamonds were first discovered by J. F. H. Custers, Physica **10**, 489 (1952); *ibid.* **20**, 183 (1954).

A11. Adsorption and Charge Transfer on Semiconductor Surfaces. H. J. KRUSEMEYER AND D. G. THOMAS, *Bell Telephone Laboratories.*—The concentration of ions and neutral atoms adsorbed on a semiconductor surface, as well as its surface potential, has been treated as a function of the pressure of surrounding gases for coverages up to one monolayer, considering the occupation of sites by both ionized and unionized atoms. Both pure gases and a mixture of two gases, one giving rise to positive, the other to negative, adions, are treated. Numerical results are obtained for semiconductors such as ZnO with a large forbidden gap and outside the intrinsic range. For a gas with N atoms per molecule and giving rise to positive adions on an n-type semiconductor, the adion density is proportional to the pressure p for very low coverages. Following a transition region the coverage becomes proportional to $P^{1/N}$ until degeneracy of the electron gas near the surface further impedes coverage increase. For gases giving rise to negative adions, the linear behavior for low coverage and the transition region are followed by a region where the ion coverage is nearly independent of gas pressure until an inversion layer is formed. From this point on the behavior is similar to that for gases causing positive ions at higher coverage. The evaluation of the energy of electronic levels, caused by the gas atoms, and the total number of adsorption sites are discussed.

A12. Minority Carrier Lifetime in p-n Junction Devices. J. R. MADIGAN, AND M. BYCZKOWSKI, *Hoffman Semiconductor Division.*—Kingston[1] and Lax and Neustadter[2] have obtained the relation between junction recovery time and lifetime for the limiting cases in which the width of the base region is either much greater than or much less than a diffusion length. In silicon-diffused junction rectifiers the case where the base width and diffusion length are comparable is common, and neither of the foregoing approximations is appropriate. A general relation between the lifetime and the recovery time has been obtained for arbitrary base widths and in general agreement with measurements on diffused junctions.

[1] R. H. Kingston, Proc. Inst. Radio Engrs. **42**, 829 (1954).
[2] B. Lax and S. F. Neustadter, J. Appl. Phys. **25**, 1148 (1954).

A13. An Anomalous Conductivity Modulation Behavior of a Pulse of Charge Carriers Drifting through a Poor Junction in p-Type Germanium. MILTON GREEN, *Signal Corps Engineering Laboratories.*—In a series circuit containing semi-

conductor, resistor, and dc power supply a transient current, δI, is generated when a pulse of charge carriers is injected into the semiconductor. For small injection in a p-type semiconductor, the results of elementary circuit theory show that the emf, $\epsilon(t)$, of the generator of the equivalent transient circuit is given by $(1+b)\int(\delta n/p)E(x)dx$, where δn is the density of the injected electronic charge. Since δI is proportional to $\epsilon(t)$, it will be large (or small) when $\epsilon(t)$ is large (or small). Therefore, δI will be large (or small) when the pulse is in regions where E/p is large (or small). In a reversed biased junction, E/p is large and a large pulse of current should be observed when the injected pulse drifts through it. For a poor germanium junction this had indeed been observed; however, in the wake of the current pulse a negative signal is observed. This means that at some point in the vicinity of the junction $(\delta n/p)$ becomes negative. When a hole pulse is drifted into this junction by injection on its positive side, the negative signal is not observed.

Thursday Morning at 10:00

Shoreham, Main Ballroom

(K. Way presiding)

Electrons and Positrons

B1. Variational Calculation of the Scattering of Electrons by Hydrogen Atoms Near Zero Energy.* Sidney Borowitz and Howard Greenberg,† *New York University.*—The cross section for the scattering of electrons by hydrogen atoms at zero energy has been calculated using a variational principle of the Hulthen-Kohn[1] type. For singlet scattering we have used a three-parameter trial function which reduces to an H^- wave function at small electron separations and which has the correct asymptotic form. To calculate triplet scattering we use an antisymmetrized version of the same trial function. The effective range for singlet scattering is determined from the scattering length already calculated and the known value of the electron attachment energy for H^-. For triplet scattering we use an energy-dependent trial function to determine the effective range. Our results are $a_s=7.746a_0$, $a_t=2.352a_0$, $r_s=3.80a_0$, $r_t=0.808a_0$, and a_0 is the Bohr radius. The total cross section at zero energy is $76.6\pi a_0^2$. The effective range formula is valid from zero energy up to about 0.04 ev.

* Jointly supported by the Office of Naval Research and Air Force Cambridge Research Center.
† Present address: City College of New York.
[1] W. Kohn Phys. Rev. **74**, 1763 (1948).

B2. Elastic Scattering of Electrons by Atomic Hydrogen.* B. Bederson, H. Malamud, and J. Hammer,† *New York University.*—An atomic beam method has been used to perform measurements on the total scattering cross sections of electrons by atomic hydrogen for voltages between 4 and 12.5 volts. An H_1+H_2 beam is produced by an rf discharge and an electron beam by an electrostatically focused electron gun. The H_1+H_2 beam is mechanically chopped (25 cps) and is made to cross the electron beam in the scattering region. The scattered electrons are collected by a Faraday chamber and the observed signal recorded by a lock-in detection system. Absolute values for the atomic cross sections are obtained by normalizing to the known molecular cross sections. The normalization requires knowledge of the atomic beam temperature and the ratio H_1/H_2. These were both measured by means of an inhomogeneous magnet velocity analyzer (Stern-Gerlach experiment). The cross sections obtained start at about 4 in units of πa_0^2 at 12.5 volts and rise rapidly to about 50 at 4 volts. At the lower energies the measured values are considerably higher than those obtained in recent calculations.[1]

* Supported by the Office of Naval Research.
† Present address: Bell Telephone Laboratories.
[1] Massey and Moiseiwitsch, Proc. Roy. Soc. (London) **A205**, 483 (1951).

B3. Technique for Measuring Polarization of Slowed Positrons.* Lorne A. Page and Milton Heinberg,† *University of Pittsburgh.*—Finite $\langle\sigma_z\rangle$ for slowed positrons should be directly reflected in the relative population, $(1+\epsilon)/(1-\epsilon)$, of $^1S_{0,0}$ and $^3S_{1,0}$ positronium formed, for field $H_z\neq 0$. To have reasonably strong *Paschen-Back* effect (12 kilogauss, e.g., implies $\epsilon=0.3$ for $n=1$ positronium) one uses large H which requires *distinguishing* experimentally between two-photon annihilation events from the two states. It has already been demonstrated[1] that in a noble gas, with suitable thermalizing additive, sufficiently old ($>3\times10^{-9}$ sec) positronium will be slow enough to yield a pronounced narrow component ($\sim2\times10^{-3}$ rad) in the two-photon angular correlation, in contrast to nascent positronium ($\sim10^{-10}$ sec old) which is on the average too fast to do so. Denoting Q_w, the ratio of two-coincidence rate at 180° for *large* field $|H|$ *vs* field zero with angular resolution w, one expects the asymmetry in rate between $\pm H$ for hypothetically complete polarization to be $\epsilon(1-Q_w/Q_\infty)$, where all three parameters are known and may be varied. Typically, Q_∞ is 1.1 and Q_w ranges to 1.5. An experiment using Na^{22} positrons emitted into one hemisphere is under way to test for residual polarization[2] in order to find out the sign of $\langle\boldsymbol{\sigma}\cdot\mathbf{v}\rangle$.

* Work done in the Sarah Mellon Scaife Radiation Laboratory and sponsored by the Office of Ordnance Research, U. S. Army.
† Now at Cornell University.
[1] M. Heinberg and L. A. Page, Bull. Am. Phys. Soc. Ser. II, 1, 168 (1956); Milton Heinberg, dissertation (to be published).
[2] Polarization at emission may be large: L. Wolfenstein (unpublished); Jackson, Treiman, and Wyld (to be published).

B4. Pair Production in the Field of an Electron by the γ-Ray Beam of the Cornell Synchrotron.* E. L. Hart, G. Cocconi, V. T. Cocconi, K. C. Rogers, and J. M. Sellen.—A 24-in. diffusion cloud chamber, filled with hydrogen to 20 atmos operating in a magnetic field of 6 kilogauss, has been placed in an 870-Mev collimated bremsstrahlung beam of the Cornell Synchrotron. Electron pair production in the field of an electron has been observed and measured for various γ-ray energies. Results will be given for the cross section, and for the energy distribution among the electrons.

* Assisted by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.

B5. Secondary Electron Emission from Surfaces Caused by Positron Bombardment. William H. Cherry, *RCA Laboratories* (introduced by G. A. Morton).—The average numbers of secondary electrons below 20-volt energy, produced from an activated magnesium-silver[1] target by bombardment with 940-volt positrons and electrons, were approximately 1.6 and 4.8, respectively. Thus the electrons are three times more efficient producers of secondary emission. With primary positrons, triple coincidence between emission of the secondary electrons and two annihilation quanta was observed. The quantitative results were derived from pulse-height distribu-

tions, the secondary electron pulse from each primary particle being amplified in a high-gain, low-background electron multiplier. The vacuum apparatus also included an electron gun, a positron accelerator, velocity selector and lens system, and a mica window for admitting positrons from external radioisotopes. Additional experiments were made with hundred-kilovolt positrons, gamma rays, ultraviolet photons, and positive ions. A very large number of positrons in the energy interval 0–5 volts, relative to the numbers in comparable intervals at somewhat higher energies, were emitted[2] from a 200-A layer of chromium on mica when irradiated by a Cu^{64} beta spectrum. This arrangement was particularly useful as a positron source for the secondary emission measurements.

[1] Zworykin, Ruedy, and Pike, J. Appl. Phys. **12**, 696 (1941).
[2] This contrasts with the negative observations on other materials of L. Madansky and F. Rasetti, Phys. Rev. **79**, 397 (1950); discussed by R. A. Ferrell, Revs. Modern Phys. **28**, 312 (1956).

B6. Angular Correlation of Annihilation Radiation in Cd Single Crystals.* L. G. Lang and N. C. Hien, *Carnegie Institute of Technology.*—Using the apparatus of Lang *et al.*,[1] the angular distribution of gamma-ray pairs arising from the annihilation of positrons in Cd single crystals has been measured as a function of crystalline orientation. A small anisotropy has been observed: the distribution corresponding to momentum in the direction of the c axis is found to be slightly wider than that corresponding to momentum perpendicular to the c axis. This agrees qualitatively with the anisotropy of the Brillouin zone. Plots of the angular distributions and mean values of momentum will be given for various orientations and will be compared with data taken on a polycrystalline sample.

* This research is supported by the National Science Foundation.
[1] Lang, DeBenedetti, and Smoluchowski, Phys. Rev. **99**, 596 (1955).

B7. Temperature Effect in the Annihilation of Positrons in Teflon.* R. L. de Zafra and W. T. Joyner,† *University of Maryland.*—The effect of temperature on the angular distribution of radiation from positrons annihilating in Teflon has been remeasured with a constant instrument resolution of one milliradian, thus resolving a possible ambiguity resulting from a change of instrument resolution in a previous set of measurements by Stewart.[1] The contribution of the narrow component, attributed to the annihilation of positronium, is found to increase with temperature; the magnitudes agree roughly with Stewart, proving that the pronounced peaking at high temperatures as seen by Stewart was not principally the result of change of instrument resolution, as might be supposed. The temperature history of the sample has no observable effect on the angular distribution at a given temperature. Similar measurements on fused quartz will be reported. The temperature dependence of the narrow component will be discussed in terms of $^3S-{}^1S$ conversion in insulators. The temperature dependence in Teflon is also being investigated with a view toward correlating the peaking rate with known structural changes in Teflon at various temperatures.

* Supported by the Department of Defense.
† Cooperative arrangement with the Department of Defense.
[1] A. T. Stewart, Phys. Rev. **99**, 594(L) (1955).

B8. Influence of Pressure on Lifetime of Positrons in Amorphous Materials. R. Stump, *University of Kansas.*—When positrons annihilate in certain amorphous materials, the decay is complex, and two mean lifetimes are observed. The longer mean life, τ_2, is associated with triplet positronium formation. The lifetimes of positrons in water, Lucite, Teflon, and polyethylene have been measured at pressures up to 60 000 lb/in.[2] No change in τ_2 occurs at these pressures in Lucite or water. In both Teflon and polyethylene, a marked decrease in τ_2 is observed with increasing pressure. The decrease in τ_2 is roughly proportional to the volume change. It is proposed that the temperature variation of τ_2 is mainly the result of the variation in density, since varying the density by pressure gives comparable lifetime charges.

B9. Positron Lifetime in Plastics as a Function of Temperature. J. G. Lundholm, Jr., John A. Bjorkland,* and A. C. Menius, Jr., *North Carolina State College.*—The long lifetime components of positronium in Lucite, nylon, polyethylene, polystyrene, and Teflon have been measured as a function of temperature between 25°C and 200°C. A millimicrosecond coincidence system employing plastic phosphors with RCA 6342 photomultipliers and a Bell and Graham type coincidence circuit was used. Special motor-driven coaxial switches and special programming circuits in conjunction with Streeter-Amet printing register allowed data to be taken over 24-hr periods. The temperature was controlled to $\pm\frac{1}{4}$°C. The results of these measurements indicate that the long lifetime component varies directly as the absolute temperature.

* Now with Cook Electric Company, Chicago.

Invited Papers

B10. Scattering of High-Energy X-Rays. E. V. Hayward, *National Bureau of Standards.* (30 min.)
B11. Thermal Broadening of Gamma-Ray Lines. P. B. Moon, *University of Birmingham, England.* (30 min.)

Thursday Morning at 10:00

Sheraton-Park, Burgundy Room

(W. A. Higinbotham presiding)

Instrumentation, Mostly Nuclear

C1. Thin-Foil Calorimetric Transmission Monitor for High-Energy Particle Beams.* L. S. Skaggs, L.† H. Lanzl, and G. T. Wood, *Argonne Cancer Research Hospital.*—A thin foil can be used advantageously to measure the current in beams of high-energy particles from accelerators by calorimetric methods. The monitor can be designed to have good sensitivity with small perturbation of the beam. Unlike ionization chambers, this type is not sensitive to the duty cycle of the accelerator, and it appears adaptable to very high currents. The sensitivity for relativistic electrons is nearly independent of energy—corrections for secondary electron escape and for the density effect nearly cancel the energy-dependent terms of the energy loss function. Thus, above 50 Mev, the response is energy-independent within $\frac{1}{2}$%. A rate monitor will be described having a sensitivity of $5\cdot10^{-10}$ amp and a time constant of 5.1 sec. An $0.5\cdot10^{-3}$ cm thick copper foil is used, and temperature rise is measured with a copper-constantan thermocouple and a chopper amplifier.

* Work performed under the auspices of the U. S. Atomic Energy Commission.

C2. A Study of the Imaging Properties of Crossed Quadrupoles. ELIAS REISMAN AND BENJAMIN M. SIEGEL, *Cornell University.*—The optical characteristics of two crossed magnetic quadrupoles have been studied experimentally, and the results obtained are found to agree well with values given by calculation.[1] The parameters of the system can be adjusted to give a short focal length lens which produces a good first-order image, free of distortion and astigmatism. For 40-kv electrons, a magnetization of 30 ampere turns, using pole pieces 7.5 cm long with bores of 2 cm, produced a focal length of 2 mm. The third-order aberrations of the system will be discussed.

[1] B. M. Siegel and E. Reisman, J. Appl. Phys. **25**, 1453 (1954).

C3. Line Profiles from Extended Sources in Homogeneous Field Ring Focusing Spectrometers. P. G. LICHTENSTEIN, *University of California, Davis.*—The analysis of a source geometry suggested by Beard[1] in a homogeneous field ring focusing beta-ray spectrometer has been performed with consideration given to methods possible for defining trajectories of rays emanating from an extended source. The results of the analysis indicate that the geometry of the trajectory-defining baffles necessitates an approximately linear relation between source extent and resolution so as to change the functional dependence between intensity at maximum and width at half maximum of the line profile. The effect of the source—solid angle relation results in a dependence of the line intensity on the 5/2 power of the resolution. The optimum source extent and profile height for a desired half-width of profile will be compared with those for geometries of DuMond[2] and Hubert.[3] An improvement of approximately a factor of two over previous geometries in intensity for a given half-width appears possible.

[1] D. B. Beard, Rev. Sci. Instr. **28**, 19 (1957).
[2] J. W. M. DuMond, Rev. Sci. Instr. **20**, 160 (1949).
[3] P. Hubert, Ann. Physik **8**, 662 (1953).

C4. Design and Test of a Uniform Magnetic Field for Use in a Precision Beta-Ray Spectrometer.* J. A. JUNGERMAN, M. E. GARDNER, P. G. LICHTENSTEIN AND C. G. PATTEN, *University of California, Davis.*—An end-corrected iron-free solenoid has been constructed which is designed to produce a magnetic field uniform to 1 part in 10^4 in a cylindrical volume 188 cm long and 65 cm in diameter. Edge-wound copper ribbon is used to fabricate the solenoid and correction coils making possible a dissipation of 7.5 kw (which corresponds to the focusing of 5-Mev electrons) with a temperature rise of 6°C. The magnetic field produced has been stabilized[1] and measured using nuclear magnetic resonance. The results of these measurements will be reported.

* Work supported in part by the U. S. Atomic Energy Commission.
[1] DuMond, Bogart, Kohl, Muller, and Wilts, Report to Research Corporation of Research and Development (March 1952).

C5. A Magnetic Analyzer for Nuclear Reaction Products.* OTTO MEIER, JR., N. R. FLETCHER, AND R. M. WILLIAMSON, *Duke University.*—A magnetic analyzer for nuclear reaction products employing a sector-shaped uniform magnetic field has been built. The shaped sectors are inserted in the 8.5-in. gap of a "C" shaped magnet with a 12-×12-in. cross section. In the notation of Cross[1] the sector parameters are $\rho = 15$ in., $\phi = 60°$, gap width = 1.5 in., $l' = 22.5$ in., $l'' = 45$ in., $\epsilon_1 = 46°38'$, $\epsilon_2 = -18°21'$, max $\alpha = \pm 3°$, max $\omega = \pm 1.6°$. The boundaries of the sector and the locations of the object and image positions were corrected for the effect of the fringing field.[2] Fringing field focusing in the direction parallel to the magnetic field is not as strong as calculated. However, the maximum image height is 2 in., the height of the scintillation detector. The magnet is capable of bending 10-Mev protons and has a maximum useful solid angle of 1/2000 of 4π steradians. When the object width is 1 mm, the observed energy resolution is 1/400. Advantages of this magnet are simplicity of construction and ease of adaptation to other sector parameters.

* Supported by the U. S. Atomic Energy Commission.
[1] W. G. Cross, Rev. Sci. Instr. **22**, 717 (1951).
[2] K. T. Bainbridge, *Part V Experimental Nuclear Physics*, (John Wiley and Sons, Inc., New York, 1953), pt. V, Vol. I.

C6. An Improved Velocity Analyzer.* M. D. WAGNER, J. A. SIMPSON, AND L. MARTON, *National Bureau of Standards.*—In order to investigate the scattered distribution of electrons in the 20- to 50-kev range with sufficient resolution in energy and angle and to provide useful information on characteristic energy losses, there is need for an electron velocity analyzer with the following charactristics: (1) energy resolution at least 1 ev and preferably 0.1 ev at an initial energy of 20–50 kev; (2) to first order, independent of power-supply instability; (3) well-defined angular acceptance of approximately 10^{-3} radian. The output should be at an energy sufficient to use fast detectors, and specimen and detector should be grounded. Also the beam-defining apertures should be no smaller than 0.1 mm. An analyzer satisfying these requirements has been constructed. It consists of a decelerator to reduce the electron energy to a few hundred volts, a double-focusing permanent magnet analyzer and a re-accelerator. The analyzer is designed to give a resolution of 0.1 ev but is limited at the present time to approximately 1 ev by the energy distribution of the initial beam. The design calculations and performance will be discussed.

* Supported by the Office of Basic Instrumentation.

C7. The Spherical Condenser as a High-Transmission Particle Spectrometer. R. D. BIRKHOFF, R. H. RITCHIE, AND J. S. CHEKA, *Oak Ridge National Laboratory.**—Charged particles leaving the inner sphere with take-off angles between α_1 and α_2 measured to the tangent plane will form an annular circle of least confusion after traveling through the central angle ϕ. The electric field is made zero beyond an annular split placed at this position. The particles then travel in straight lines back to an extension of the line joining the point of departure and the center of the spheres and enter a coaxial cylindrical counter placed along this line. The transmission and energy resolution have been determined analytically with small-angle approximations for ϕ between 160° and 180° and graphically for ϕ between 120° and 160°. Where highest transmission is important, a choice of angle ϕ of 120° yields a transmission of 29% at an energy resolution of 7%. For highest resolution and a ϕ of 170° the transmission is 4.4% and energy resolution 0.19%. Post acceleration appears feasible just beyond the annular slit. The device may be useful also as a low-energy x-ray spectrometer using a photoelectron radiator struck by an x-ray beam directed toward the center of the spheres. Finite source limitations, line profile shape, and anti-scatter baffles will be discussed.

* Operated by Union Carbide Nuclear Company.

C8. Particle Identifiation in Fine Grained Emulsions.* I. AHMAD,† P. DEMERS AND J.-L. MEUNIER,‡ *Universite de Montréal.*—Linear grain density is useful between 1 and more than 40 times minimum ionization (14 to ~300 grains per 100 μ). Grains in blobs can be counted with confidence as far as 3 and even 4 grains, and blob length analysis reveals corresponding maxima: 1 grain/length 0.18 μ, 2/0.45, 3/0.88, 4/1.12, 5/1.32. Gap density, fractional gap length, average gap, and blob lengths are useful as far as $I = 300$ times minimum and over. Maximum, of 135 gaps per 100 μ, occurs at $I = 12$. Beyond $I = 600$, gaps are absent but track width, then raising above 0.18 μ, may be useful as a measure of ionization. The application to the identification of slow tracks shorter than 100 μ will be discussed. Such ionization measurements, and also scattering measurements, etc., are feasible with great accuracy

over the whole range of practically any kind of track. This may be useful in comparing the masses of single particles.[1]

* Supported by National Research Council.
† Colombo Plan Scholar.
‡ Present address: Collège Militaire, Saint-Jean (Québec).
[1] See Demers and Meunier, Ann. ACFAS **21**, 49 (1955); Ahmad and Demers, *ibid.*, 23 (1957); Demers, Can. J. Phys. **32**, 538–554 (1954).

C9. A WF_6 Bubble Chamber.* J. H. MULLINS, E. D. ALYEA, L. R. GALLAGHER, J. K. CHANG, AND J. M. TEEM, *California Institute of Technology.*—High density, high Z liquids, such as Xe, appear to be very useful as bubble chamber fluids.[1] However, the cost and availability of Xe preclude its extensive use, so a search was initiated for other heavy liquids. Following a suggestion of Glaser, we have tested $SnCl_4$ and WF_6 successfully. WF_6 was operated in a 1.5-in. metal chamber with quartz windows at a temperature of 149°C and vapor pressure of 426 psi. Lower density tracks were observed at temperatures as low as 136°C. No etching of glass or quartz was observed at the operating temperatures after suitable drying and distillation of the WF_6. Inconel and Monel metals were also unaffected. The measured density at the operating temperature of 2.42 ± 0.3 indicates a radiation length of 3.8 cm and a 15% higher stopping power than Xe. $SnCl_4$, which operated at 265°C and 275 psi, and $SnBr_4$ were less desirable because of corrosion and sealing problems at their higher operating temperatures. A 12-in. WF_6 bubble chamber is under construction.

* This work was supported in part by the U. S. Atomic Energy Commission.
[1] Brown, Glaser, and Perl, Phys. Rev. **102**, 586 (1956).

C10. Use of Photon Counters in Investigation of Photosensitive Surfaces.* H. O. ALBRECHT AND C. E. MANDEVILLE, *Bartol Research Foundation.*—Ultraviolet sensitive Geiger counters show a marked increase in photosensitivity and a shift in response toward longer wavelengths after continued use or after a glow discharge in liquid nitrogen. Hydrogen containing fillings show marked effects whereas little change occurs in counters filled with pure oxygen or nitrogen or other gases. Cathodes of copper, platinum, silver, and electrically conducting glass gave similar results. It is conjectured that this photosensitivity resides in an adsorbed layer of molecules or radicals on the counter cathode. Recombination in the layer may explain the presence of spurious counts. Some preliminary data will be presented.

* Assisted by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.

C11. Vernier Chronotron.* H. W. LEFEVRE AND J. T. RUSSELL, *Hanford Laboratories.*—A multichannel time difference analyzer with a digital output has been developed for measurements in the millimicrosecond region. The analyzer consists of two circulating transmission lines, with a single fast coincidence circuit between them, and associated gating circuits. Each circulating line is a precisely trimmed coaxial cable with its ends joined by a noninverting, saturating pulse amplifier. A circulating pulse produces time marks at the input to the coincidence circuit. By making the circulation period of the two lines slightly different, the time marks are made to arrive at a slightly different frequency, thus duplicating the action of an ordinary vernier. To determine the interval between insertion of the pulses into the lines, it is only necessary to count the number of circulations before coincidence and multiply by the difference in period of the lines. This analyzer has a capacity of 240 channels of 1-millimicrosecond information or a correspondingly larger number of narrower channels. The number of very narrow channels is limited by a slow jitter in the period difference of about 10^{-4} mμ. Analyzing speed is 300 mμ per channel. This analyzer has been developed primarily for measurement of neutron energy by time of flight.

* Work performed under the auspices of the U. S. Atomic Energy Commission.

C12. Information Efficiency, a Figure of Merit for Radiation Detectors. RICHARD L. PETRITZ, *U. S. Naval Ordnance Laboratory.*—The performance of detectors has been discussed using information theory.[1] That work is extended by assuming the detector to have a responsivity with a single time constant τ, and a noise spectrum of one of three classes: (a) flat, (b) $1/f$, or (c) single time constant spectrum. Exact expressions are derived for the information capacity, C_n (bits/sec), and for the noise-equivalent power, P_n, as a function of band width. These are used to evaluate a quantity which we call information efficiency, $\vartheta_n = C_n/P_n$ (bits/sec)/watt, which is a measure of the bits of information received per joule of incident energy. ϑ_n increases as Δf^0 for $\Delta f < f_\tau (f_\tau = \frac{1}{2}\pi\tau)$; it has a maximum near $\Delta f = f_\tau$; then it decreases for $\Delta f > f_\tau$. We can express ϑ_n in terms of either the maximum detectivity D_{1m}, or Jones' S, or Jones' figures of merit k_1 and k_2 along with the band width and time constant. In special cases ϑ_n is equal to D_{1m}, k_1, k_2 or $1/S\tau$ (McAlister relation). However, information efficiency is a more general figure of merit than these and can be used for all types of detectors and under all conditions.

[1] R. L. Petritz in *Photoconductivity Conference*, edited by Breckenridge, Russell, and Hahn (John Wiley and Sons, Inc., New York, 1956), p. 49.

THURSDAY MORNING AT 10:00

Sheraton-Park, Caribar-Mural Room

(M. L. GOLDBERGER presiding)

Theoretical Physics I: High-Energy Physics

CA1. Study of the Hypertriton.* B. W. DOWNS, *Cornell University.*—A variation method is used to set an upper limit on the strength of the Λ^0 nucleon interaction required to account for the observed binding energy of the hypertriton. The proton and neutron are assumed to be in a triplet S state, and the Λ^0 nucleon (n and p) interaction is taken to be a Yukawa potential. The product of the depth of the required potential and the square of the range decreases with increasing range. For a range as small as the K meson Compton wavelength, the conventional well-depth parameter for a system of a Λ^0 and one nucleon is less than 0.8, indicating that the hyperdeuteron is far from being bound.[1] If the range is this short, the hypertriton is a nearly symmetric structure more compact than the triton despite its much smaller binding energy. Results obtained are in general agreement with the preliminary results of Dalitz.[2]

* Assisted by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.
[1] See G. H. Derrick, Nuovo cimento **4**, 565 (1956).
[2] R. H. Dalitz, *Proceedings of the Sixth Rochester Conference on High Energy Nuclear Physics* (Interscience Publishers, Inc., New York, 1956), p. V–40. The present work is a continuation of work started by Dalitz and the author at Birmingham.

CA2. Binding of Hyperfragments. MURRAY PESHKIN AND LAURIE M. BROWN, *Northwestern University.*—Observed hyperfragment binding energies have been used to calculate the Λ^0-N interaction strength, assuming short-range central ordinary forces.

Species	${}_\Lambda H^4$,${}_\Lambda He^4$		${}_\Lambda He^5$		${}_\Lambda Li^7$		${}_\Lambda Be^9$	
$a(f)$	1.84	1.67	1.61	1.40	2.78	2.67	3.04	2.94
U(Mev f^3)	824	720	715	590	1480	1390	1910	1800

The shape and the radius a of the nuclear core were obtained as follows: ${}_\Lambda H^4$ and ${}_\Lambda He^4$, Gaussian with Coulomb energy radius; ${}_\Lambda He^5$, ${}_\Lambda Li^7$, ${}_\Lambda Be^9$, electron scattering data for He^4, Li^6, Be^9. The smaller radius for each species is corrected for the proton charge size. U is the volume integral of the interaction potential. The results for H and He agree with Dalitz's earlier calculations.[1] While the Li result is consistent with his suggested spin dependence (zero or repulsive force in the disfavored alignment) the Be case is clearly inconsistent with any such force, unless the assumed radius is reduced by 30%. These conclusions are independent of reasonable variations of the assumed radii and binding energies, except for the radius of the ${}_\Lambda Be^9$ core.

[1] R. H. Dalitz, *Proceedings of the Sixth Annual Rochester Conference* (Interscience Publishers, Inc., New York, 1956).

CA3. Relationship between Phase Shift Analysis and Classical Black Sphere Model of High Energy p-p Scattering. W. RARITA* AND P. SCHWED, *RIAS.*—The range of applicability of the formal black sphere diffraction model to p-p scattering in the high energy region under 1 Bev has been determined by consideration of the experimental results of the Brookhaven group.[1] By taking this model literally an expression for $f(\theta)$, the angular dependence of the scattered wave in the asymptotic region, has been obtained and represented in terms of Legendre polynomials to determine a phase shift analysis for this case. The comparison with the earlier phase shift analysis[2] made directly upon the experimental data will be presented and the physical significance discussed.

* Also at Brooklyn College.
[1] Smith, McReynolds, and Snow, Phys. Rev. **97**, 1186 (1955).
[2] W. Rarita, Phys. Rev. **104**, 221 (1956).

CA4. Phenomenological Two-Nucleon Potential below 150 Mev.* P. S. SIGNELL AND R. E. MARSHAK, *University of Rochester.*—Gartenhaus[1] has derived a charge-independent two-nucleon potential using Chew's cut-off model. The Gartenhaus potential (consisting of central and tensor parts) gives a good fit to the low-energy data, but is in sharp disagreement with nucleon-nucleon scattering experiments in the 90–150 Mev region. Since large modifications of the central and tensor potentials do not improve the situation[2] and since there are many indictions of nuclear spin-orbit forces, the effect of adding a short range, singular spin-orbit term to the Gartenhaus potential has been investigated. Exact phase shifts were computed using an IBM 650. If the added spin-orbit potential has the same sign as in shell theory, the agreement with both the polarized and unpolarized scattering data at 90 and 150 Mev is greatly improved. The opposite sign for the spin-orbit force yields complete disagreement with experiment. At energies above 200 Mev, the comparison becomes progressively worse for the same choice of parameters. An attempt is being made to improve the higher energy predictions.

* Supported in part by the U. S. Atomic Energy Commission.
[1] S. Gartenhaus, Phys. Rev. **100**, 900 (1955).
[2] See M. S. Wertheim *et al.*, Phys. Rev. **104**, 764 (1956); H. Gelernter, Phys. Rev. (to be published).

CA5. Determination of Pion-Nucleon Coupling from the Annihilation of Slow Antiprotons in Hydrogen. RICHARD A. FERRELL, *University of Maryland.*—Although the pseudoscalar (PS) coupling of the pion and nucleon fields is generally preferred, there does not seem to be any conclusive evidence to rule out the alternative of pseudovector (PV) coupling. Because the mesic charge of an antinucleon is opposite that of a nucleon for PS but the same for PV coupling, the annihilation of slow protons in hydrogen distinguishes between these two types. At moderate distances the one-meson exchange potential can be expected to dominate in the proton-antiproton interaction and is attractive only for states which are jointly even in spin and isotopic spin. By the selection rule of Lee and Yang[1] S states of this type annihilate with an even number of mesons. The annihilation in odd S states, which would give an odd number of mesons, is inhibited by the strong repulsion of the potential. For PV coupling the situation would be reversed and the decay would be mainly into odd munbers of mesons, assuming again only annihilation in S states.

[1] T. D. Lee and C. N. Yang, Nuovo cimento **10**, 3, 749 (1956).

CA6. Pion Production in Pion-Nucleon Collisions.* R. M. STERNHEIMER AND S. J. LINDENBAUM, *Brookhaven National Laboratory.*—The single production of pions occurring in pion-nucleon collisions at incident energies below ~1.5 Bev is assumed to arise from the excitation of the nucleon to the $T=J=\frac{3}{2}$ isobaric state by the incident pion, followed by the subsequent decay of the isobar into a nucleon and a pion. The probability for forming isobars with various mass values m (=total energy in isobar rest system) has been related to the total π^+-p scattering cross section and to the available phase space by a method similar to that previously used for pion production in nucleon-nucleon collisions.[1] Assuming conservation of isotopic spin, the relative frequencies of the various pion charge states have been obtained. The predictions of the present model for the pion and nucleon momentum spectra and for the angular correlations will be compared with the data of Walker *et al.*[2] at 1.0 Bev and the data of Eisberg *et al.*[3] at 1.37-Bev incident pion energy.

* Work performed under the auspices of the U. S. Atomic Energy Commission.
[1] S. J. Lindenbaum and R. M. Sternheimer, Phys. Rev. (to be published).
[2] Walker, Hushfar, and Shephard, Phys. Rev. **104**, 526 (1956).
[3] Eisberg, Fowler, Lea, Shephard, Shutt, Thorndike, and Whittemore, Phys. Rev. **97**, 797 (1955).

CA7. Regular Pion-Hydrogen Phase Shifts.* H. Y. CHIU AND E. LOMON, *Cornell University.*—The meson scattering data from 120–217 Mev has been examined to obtain phase shifts varying simply with c.m. momentum. δ_3 is chosen to be the straight-line extrapolation from low-energy data. δ_{33} is close to the Track 1 solution of de Hoffman *et al.*[1] δ_{13} increases monotonically. δ_{31} and δ_{11} have small positive values at 169 Mev and thereafter decrease monotonically. δ_1 is not closely determined. It can vary between the straight line extrapolation from zero energy, and a curve which increases to only half the straight line value at 194 Mev. δ_{33} and δ_{31} extrapolate smoothly to the phase shifts obtained by Margulies[2] at higher energies. The resulting angular distributions and total cross sections are in agreement with experiment except for the asymmetry at 217 Mev. The D-state contribution is examined to determine if it is possible to improve the asymmetry at 217 Mev, and also to have $\delta_{31}\approx\delta_{13}$ at 194 and 217 Mev.

* Supported in part by joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.
[1] de Hoffmann, Metropolis, Alei, and Bethe, Phys. Rev. **95**, 1587 (1954).
[2] R. S. Margulies (private communication).

CA8. Dispersion Relations for Forward Pion-Nucleon Scattering.* D. A. GEFFEN, *Carnegie Institute of Technology.*—A rigorous proof of the dispersion relations for forward scattering, given by Jost,[1] is applied to the case of pseudoscalar mesons and spin one-half nucleons. It is found that Eqs. (2.13) and (2.14) given by Goldberger[2] can be obtained exactly by the Jost procedure. One can also show the equivalence be-

tween the Jost and Symanzik[3] proofs for the case considered by Symanzik of mesons inteacting with scalar nucleons.

* Supported in part by the U. S. Atomic Energy Commission.
[1] Private communication, September, 1956.
[2] Goldberger, Miyazawa, and Oehme, Phys. Rev. **99**, 986 (1955).
[3] K. Symanzik, "A derivation of dispersion relations for forward scattering" (preprint).

CA9. Dispersion Relations for K-Nucleon Scattering.* J. J. SAKURAI, *Cornell University.*—Dispersion relations for the scattering of spin-0 K particles by nucleons are derived along the lines of the Nambu-Chew formalism[1] under the assumption that strangeness and isotopic spin are sufficient to characterize the internal state of the K particle. A theorem analogous to the crossing theorem in pion-nucleon scattering is shown to hold between scattering matrices of *opposite* strangeness. "Bound state" contributions arise at the c.m. energies equal to the Λ and Σ masses, and have the structure of Born terms consistent with the conservation of strangeness. Since energy-momentum-conserving *real* processes such as $K^- + p \rightarrow \Lambda^0 + \pi^0$ can occur at energies *below* the zero projectile energy $M_N + \mu_K$, there are continuum contributions starting at $M_\Lambda + \mu_\pi$, for which analytic continuations are necessary. If the spin of the $Y (Y = \Lambda$ or $\Sigma)$ and the relative parity of the Y and the K are unspecified, two constants appear that characterize the strength of the KYN interaction. The final dispersion equations reveal a profound asymmetry between the K^+-nucleon interaction and the K^--nucleon interaction arising from the conservation of strangeness.

* Supported in part by a joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.
[1] Y. Nambu, Phys. Rev. **100**, 394 (1955); G. F. Chew in *Encyclopedia of Physics* [Springer-Verlag, Berlin (to be published)].

CA10. Bound State Contribution to Dispersion Relations for the Scattering Matrix.* JAMES M. KNIGHT† AND JOHN S. TOLL, *University of Maryland.*—Previous derivations[1] of the dispersion relations for the scattering matrix for a relativistic particle scattered by a fixed, finite, spherically symmetric scatterer can be modified to include interactions which permit bound states. A typical bound state of energy $\hbar\omega_B$ introduces a simple pole at $\omega = \omega_B$ in the corresponding element of the scattering matrix. For the ground state, this pole lies on the real frequency axis; to eliminate this singularity, a factor $(\omega - \omega_B)$ is introduced, which adds one arbitrary constant to the resulting dispersion relations.[2] Metastable states correpond to singularities in the lower half of the complex frequency plane, which cause no alteration in the derivation or final form of the dispersion relations. Examples and applications will be discussed.

* Assisted by the U. S. Air Force Office of Scientific Research.
† National Science Foundation Fellow.
[1] Toll, Wong, and Knight, Bull. Am. Phys. Soc. Ser. II, **2**, 13 (1957).
[2] J. S. Toll, Phys. Rev. **104**, 1760 ff. (1956), Sec. 5(b).

CA11. Dispersion Relations for Nonrelativistic Particles.* DAVID Y. WONG,† *University of Maryland.*—If the wave function of a nonrelativistic particle satisfies the Schrödinger equation with a velocity independent potential, then its scattering amplitudes (and the S matrix in general) satisfy the same dispersion formulas as those derived for the scattering of light.[1] In the present derivation, the validity of a perturbation expansion and certain integrability of the potential are assumed, and the requirement of the outgoing wave Green's function replaces the condition of strict causality for the scattering of light. The scattering amplitude for fixed momentum transfer is also shown to satisfy the dispersion relations. If the potential possesses bound states, then all the dispersion formulas are modified to include residue terms corresponding to singularities on the positive imaginary axis of the momentum plane. The necessity of these modifications are related to the divergence of the perturbation series for small wave numbers. Essential singularities of the S matrix resulting from exponential-type potentials give no additional contribution to the dispersion formulas.

* Supported by the U. S. Air Force.
† Frank M. Shu Fellow.
[1] David Y. Wong and John S. Toll, Ann. Phys. (to be published).

CA12. Covariant Statistical Mechanics of Multiple Boson Production. A. O. BARUT, *Syracuse University.*—The statistical theory of multiple meson production is formulated in a covariant form, i.e. the model of statistical equilibrium envisaged is the same for all Lorentz frames. Covariant grand canonical ensembles are used and all the conservation laws are considered The formation of intermediate isobaric states can also be taken into account. Energy and angular distribution of bosons, the limitations of the statistical method and its relation to the field theory will be discussed.

THURSDAY MORNING AT 10:00

Sheraton-Park, Continental Room

(W. F. HORNYAK presiding)

Interactions of Medium-Weight Nuclei

D1. Measurements of Proton Strength Functions.* J. P. SCHIFFER AND L. L. LEE, JR., *Argonne National Laboratory.*—The average yield from (p,n) reactions was used to obtain values of the s-wave proton strength function, $\bar{\gamma}_p^2/\bar{D}$, of the compound nuclei. It was assumed that these reactions proceed primarily by way of a compound nucleus. Sufficiently low bombarding energies were chosen to insure that the compound nuclei were formed predominantly by s-wave protons. Measurements have been performed for twelve odd-mass nuclei between $A = 37$ and 90. An increase by a factor of three in the value of $\bar{\gamma}_p^2/\bar{D}$ is indicated in going from $A \sim 40$ to $A \sim 65$. Further studies, particularly for $A > 65$, are in progress. These results may be compared to similar work with inelastic proton scattering,[1] and to measurements of $\Gamma n^0/\bar{D}$ from neutron scattering experiments.

* Supported by the U. S. Atomic Energy Commission.
[1] Schiffer, Davis, and Prosser, Bull. Am. Phys. Soc. Ser. II, **2**, 60 (1957).

D2. Cross Sections and Thresholds for (p,n) Reactions in Intermediate Nuclei. C. H. JOHNSON, A. GALONSKY, AND J. P. ULRICH,* *Oak Ridge National Laboratory.*—Absolute cross sections for (p,n) reactions have been measured for 12 intermediate nuclei form Cl^{37} to Nb^{93} for proton energies from threshold to about 500 kev above threshold. Neutrons were detected by a group of BF_3 counters embedded in paraffin surrounding the target. The cross sections for V^{51} were also measured by comparing the activation produced in a large $MnSO_4$ solution with that by a standard Sb-Be source.[1] These cross sections for V^{51} determined the efficiency as a function of neutron energy for the counter assembly. Cross sections range from 10^{-25} cm^2 just above threshold for $Nb^{93}(p,n)Mo^{93}$ to 4×10^{-26} cm^2 at 500 kev above threshold for $Cl^{37}(p,n)A^{37}$. This range of cross sections results primarily from the variation in Coulomb barrier; a comparison will be made with the statistical theory.[2] For the twelve reactions, thresholds previously

unobserved are: $Se^{77}(p,n)Br^{77}$, 2175±4 kev; $Se^{82}(p,n)Br^{82}$, <930 kev; and $Nb^{93}(p,n)Mo^{93}$, <1300 kev. A new measurement of the Sb^{124} half-life, 60.1±0.5 days, was determined by comparison of two Sb-Be sources calibrated[1] at times separated by 265 days.

* 1956 summer participant from the University of Michigan.
[1] We are grateful to J. A. De Juren and J. Chin for these calibrations at the National Bureau of Standards.
[2] W. Hauser and H. Feshbach, Phys. Rev. **87**, 366 (1952).

D3. Photodisintegration of Neon. J. B. Warren* and H. J. Hay,† *Australian National University, Canberra.*—A proportional counter, filled to 4 atmos with pure neon, and a cylindrical gridded ionization chamber, filled to 9 atmos with neon containing some helium, have been irradiated with the γ-ray flux from a thick lithium target bombarded with 500 kev protons. Pulse-height analysis led to the assignment of the following photodisintegration cross sections: $Ne^{20}(17.6, \alpha)O^{16}$, $0.47\ 10^{-31}$ cm² to ground state of O^{16}, $6.3\ 10^{-31}$ to the 6.06 and 6.14 Mev levels, $17\ 10^{-31}$ to the 6.91 and 7.12 Mev levels, $Ne^{20}(14.8, \alpha)O^{16}$, $0.81\ 10^{-31}$ to ground level, about $10\ 10^{-31}$ to 6.06 and 6.14 Mev levels: $Ne^{20}(17.6, p)F^{19}$, $200\ 10^{-31}$ to ground and 110, 197 kev, low-lying levels of F^{19}, about $30\ 10^{-31}$ to 1.35 Mev level: $Ne^{22}(17.6, \alpha)O^{18}$, 7.2 to 10^{-31} to ground level. The $Ne^{20}(\gamma,\alpha)O^{16}$ cross sections are in good accord with the selection rules for photodisintegration of an even-even nucleus, as deduced by Gell-Mann and Telegdi.

* Now back at University of British Columbia.
† Now at A.E.R.E., Harwell.

D4. 7.5-Mev Elastic Proton Scattering.* N. S. Wall, *MIT.*—We have recently measured a series of elastic-proton angular distributions at 7.5-Mev proton energy from selected elements between Al and In.[1] We wish to show that if one assumes that nearby elements are all represented by the same complex-potential well that the differences between adjacent elements can be interpreted in terms of the compound-elastic scattering contribution. In particular even-even nuclei show a larger effect of this compound-elastic scattering because of two facts. The first is that, as has been demonstrated,[2] the effect of the higher (p,n) thresholds reduces the number of exit channels available for neutron emission by the compound nucleus. Secondly, the number of levels in the vicinity of the ground state of even-even nuclei is much lower, and therefore, assuming the branching to any one state depends only upon the total number of states available, the compound-elastic contribution to the ground state will be greater for such nuclei.

* This work was supported in part by a joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.
[1] W. F. Waldorf, thesis, MIT (1956).
[2] C. A. Preskitt, Bull. Am. Phys. Soc. Ser. II, **2**, 33 (1957).

D5. Further Evidence for a Collective Model for Al^{25}. D. A. Bromley, H. E. Gove, A. E. Litherland, and E. Almqvist, *Chalk River Laboratories.*—The strong-coupling collective model for Al^{25} requires the existence of a 7/2+ fourth member of the $K=1/2$ rotational band based on the 1/2+ first excited state at an excitation of about 2.8 Mev. Detailed coincidence measurements at the 1.66-Mev resonance in the $Mg^{24}(p,\gamma)Al^{25}$ reaction have shown three new primary radiations of 1.16, 2.07 ,and 2.27 Mev from the 5/2+, 3.88-Mev capturing state to states at 2.72, 1.81, and 1.61 Mev. That to the 1.81-Mev state is in coincidence with the previously determined cascade de-excitation of this state; the observation of 1.61- and 2.27-Mev radiations in coincidence corroborates the previous assignment of the 1.61-Mev radiation to the de-excitation of a 1.61-Mev state in Al^{25}. The 1.16-Mev radiation is in coincidence with a prominent gamma ray of about 1.80 Mev and weaker radiations of 1.36 and 2.72 Mev. This 1.80-Mev radiation can only in part be attributed to de-excitation of the 1.81-Mev state since the corresponding 1.36-Mev cascade is too weak. We conclude that a new state in Al^{25} at an excitation of 2.72±0.040 Mev is involved which may be the analog of the 2.742-Mev state in Mg^{25} which does not show a characteristic stripping pattern in the $Mg^{24}(d,p)Mg^{25}$ reaction, suggesting high spin. The new Al^{25} state de-excites strongly via the 3/2+ state at 0.95 Mev and weakly via the 5/2+, 1.81-Mev state and to the 5/2+ ground state.

D6. Evidence for a $J=2+$ Assignment for the Second Excited State of Si^{28}. H. E. Gove, A. E. Litherland, and E. B. Paul, *Chalk River Laboratories.*—The reaction $Al^{27}(p,\gamma\gamma)$ has been employed to measure the energy, gamma-ray branching, and spin and parity of the second excited state of Si^{28}. The measurements were made at the well-known resonance at 933 kev. No alpha particles are emitted at this resonance[1] and direct gamma-ray transitions to the ground state are less than 1/4% of those to the first exicted state in intensity and the angular distribution of the latter has a 5% P_2 term. This information along with elastic scattering data[2] indicates mainly s-wave formation and an assignment of 3+ for the resonance. Transitions are observed to the second excited state of Si^{28} with an intensity of about 12% of those to the first excited state at 1.78 Mev. Coincidence measurements indicate that the second excited state has an energy of 4.60±0.05 Mev and that it emits gamma rays with approximately equal probability to the ground and first excited states. A coincidence angular correlation measurement of the 4.6 Mev gamma ray with respect to the primary showed isotropy to within 5% and this measurement combined with the branching ratio favors an assignment of 2+ for this second excited state.

[1] Shoemaker *et al.*, Phys. Rev. **83**, 1011 (1951).
[2] Bender *et al.*, Phys. Rev. **76**, 273 (1949).

D7. Low-Energy Levels of Al^{27} from the Reaction $Al^{27}(pp'\gamma)Al^{27}$. E. Almqvist, D. A. Bromley, H. E. Gove, and A. E. Litherland, *Chalk River Laboratories.*—The yields of gamma radiation of 0.84 and 1.01 Mev from the $Al^{27}(pp'\gamma)$-Al^{27} reaction have been measured for incident proton energies in the range 1.4 to 2.8 Mev. The 0.175-Mev cascade transition from the 1.01-Mev to the 0.84-Mev level in Al^{27} was detected in coincidence with a voltage gate set on the 0.84 radiation; the triple angular corelation of this radiation was isotropic to within 5%. These measurements indicate that this cascade constitutes a 2.3±0.3% branch in the de-excitation of the 1.01-Mev level in agreement with the observations of Lyon and Lazar.[1] At all resonances examined thus far, the 0.84-Mev radiation had isotropic angular distributions while the 1.01-Mev radiation at some of these had $P_2(\cos\theta_\gamma)$ terms which together with the Mg^{27} beta-decay measurement[1] fixes the spin of the 1.01-Mev state at 3/2 and strongly suggest ½ for that at 0.84. Comparison of these results with those from neighboring nuclei and with the predictions of current nuclear models will be presented.

[1] W. S. Lyon and N. H. Lazar, Phys. Rev. **101**, 1324 (1956).

D8. Proton Gamma Angular Correlations in the $Si^{28}(d,p\gamma)^{29}$ Reaction.* H. A. Hill and J. M. Blair, *University of Minnesota.*—The $p-\gamma$ angular correlation has been measured for proton groups from the $Si^{28}(d,p\gamma)Si^{29}$ reaction corresponding to the 1.28 and 2.03 Mev levels of Si^{29}. In what follows, E_d is the deuteron energy; α is the angle between the proton detector and deuteron beam; θ is the angle between Si^{29} recoil and γ-ray directions; ϕ is the angle between two planes, one containing the Si^{29} recoil and deuteron beam and the other containing the Si^{29} recoil and γ-ray directions; and $W(\theta,\phi)$ is the angular correlation function. Assuming $W(\theta,\phi)$ has the form $1+a\cos^2\theta$

for the 1.28-Mev level, we find for $E_d=2.90$ Mev, $\alpha=35°$, and $\phi=0°$, 45°, 135°, 225°, and 315°, that $a=-0.04\pm0.08$, 0.06 ± 0.07, -0.02 ± 0.05, -0.06 ± 0.06, and -0.01 ± 0.03, respectively. The results obtained for the same level with $E_d=2.90$ Mev and $\alpha=135°$ are also consistent with this degree of isotropy. Allen *et al.* obtained substantially different results for the 1.28-Mev level with $E_d=9$ Mev. If we assume for the 2.03-Mev level that $W(\theta,\phi)=1+a\cos^2\theta+b\cos^4\theta$, we find for $E_d=2.90$ Mev, $\alpha=135°$, and $\phi=45°$ that $a=1.63\pm0.18$ and $b=-1.54\pm0.18$. For the same level we observed that $W(\theta,\phi)$ has a ϕ dependence such that $W(45°,0°)/W(45°,180°)=1.13\pm0.06$.

* This work supported in part by the Office of Naval Research and the U. S. Atomic Energy Commission.

D9. Nuclear Levels in P^{30} and S^{32}.† C. H. Paris, *MIT*, and C. Van der Leun and P. M. Endt, *Utrecht University*.—The proton and alpha-particle groups resulting from the deuteron bombardment of thin Sb_2S_3 targets have been studied at angles of observation of 90 and 130° and at a deuteron energy of 6.55 Mev. The deuterons were accelerated by an electrostatic generator, and the secondary charged particles were analyzed with a broad-range magnetic spectrograph and detected in nuclear emulsions. The Q value of the $S^{32}(d,\alpha)P^{30}$ reaction is 4.89 Mev, and levels in P^{30} are observed at (0.69), 0.71, 1.45, 1.97, 2.53, 2.72, 2.84, 2.94, 3.02, 3.73, 3.84, 3.93, 4.15, (4.19), 4.24, 4.31, and 4.39 Mev. The group leading to the level at 0.69 Mev had at 90° an intensity of 10% of the group leading to the 0.71-Mev level, while the intensity at 130° was smaller than 3%. The intensities of the groups leading to the 2.94- and 4.19-Mev levels were about 30% of the average intensity of the other groups. The low intensity of the group leading to the level at 0.69 Mev can be explained by assuming that this level is the expected low-lying $T=1$ level in P^{30}. This assumption is in agreement with recent experiments on the $S^{32}(p,\gamma)P^{33}$ reaction. The Q value of the $S^{32}(d,p)S^{33}$ reaction is 6.41 Mev.

† This work was sponsored in part by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.

D10. Excitation Function for the Reaction $Ca^{40}(p,p'\pi)$ and Levels in Sc^{41}.* R. D. Bent, T. H. Kruse, and L. J. Lidofsky, *Columbia University*.—The yield of electric monopole pairs from the $Ca^{40}(p,p'\pi)$ reaction has been measured as a function of bombarding energy from $E_p=4.1$ to 6.0 Mev. The pairs, resulting from the decay of the 0^+ first excited state of Ca^{40} to the 0^+ ground state, were detected with a "well" scintillation pair spectrometer.[1] Weak resonances (peak yield$\cong10^{-8}$ pairs/proton) were observed at 4.42, 4.74, and 4.90 Mev bombarding energy. Resonances about 20 times stronger were observed at $E_p=5.02$, 5.09 Mev and higher energies. Seventeen resonances were observed between 5.0 and 6.0 Mev bombarding energy. All widths were less than the target thickness of 28 kev. Preliminary estimates have been made for the reduced inelastic partial widths, γ^2, assuming $l=0$ incoming and outgoing protons and $R=1.2\times10^{-13}A^{\frac{1}{3}}$ cm. These values range from 8×10^{-11} to 3×10^{-13} kev cm, corresponding to $10^{-3}-10^{-4}$ of the Wigner independent particle limit. The average value, γ_{kc}^2 for all states is 1.5×10^{-11} kev-cm. This gives for the strength function, $\gamma_{kc}^2/\bar{D}$ a value of 6×10^{-14} cm, where $\bar{D}=240$ kev has been taken for the average level spacing. These estimates are thought to be accurate to within about a factor of 2.

* This work was partially supported by the U. S. Atomic Energy Commission.
[1] Kruse, Bent, and Eklund, Bull. Am. Phys. Soc. Ser. II, **2**, 29 (1957).

D11. Energy Levels of K^{40}.† H. A. Enge and D. H. Weaner, *MIT*.—Using the MIT-ONR broad-range spectrograph, the reaction $K^{39}(d,p)K^{40}$ has been studied at fourteen reaction angles from 10 to 130° and with an input energy $E_d=6.0$ Mev. The target was natural KI (6.8% K^{41}) on Formvar. A large number of proton groups were observed. Tentative information about ten relatively intense groups that can be assigned to K^{40} is given below. The orbital angular momenta l_n of the captured neutrons have been found by stripping analysis of the angular distribution data.

$l_n=3$	Q(Mev)	5.566	5.539	4.773	4.681		
	Max counts	134	143	105	197		
$l_n=1$	Q(Mev)	3.524	3.502	3.468	2.945	2.903	2.825
	Max counts	4300	4000	3000	1150	50	120

The Q values for the first four groups are in good agreement with previous measurements by Buechner *et al.*[1] The spin assignments previously[2] given for these four groups appear to be in accordance with the relative intensities (maximum counts) given above.

† This work has been supported in part by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.
[1] Buechner, Sperduto, Browne, and Bockelman, Phys. Rev. **91**, 1502 (1953).
[2] H. A. Enge, Phys. Rev. **94**, 730(L) (1954).

D12. Excited States of Co^{59} and Fe^{56}.† M. Mazari, A. Sperduto, and W. W. Buechner, *MIT*.—Thin cobalt targets have been bombarded with protons from the ONR accelerator, and the proton and alpha-particle groups were studied with the broad-range spectrograph. Observations were made at several different angles and bombarding energies. From the proton groups, forty levels in Co^{59} were measured in the region of excitation up to 3.7 Mev, the first six of which are at 1.097, 1.189, 1.289, 1.432, 1.458, and 1.479 Mev. Of these, only the first and third had been previously reported. The ground-state Q value for $Co^{59}(p,\alpha)Fe^{56}$ is 3.242 ± 0.012 Mev. Six other alpha-particle groups were observed and the corresponding excitation energies in Fe^{56} are in excellent agreement with those obtained from studies[1] of $Fe^{56}(p,p')$.

† This work has been supported in part by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.
[1] W. W. Buechner and A. Sperduto, Bull. Am. Phys. Soc. Ser. II, **1**, 39 (1956).

D13. Angular Distributions of Protons Scattered from In^{115}.† R. D. Sharp* and W. W. Buechner, *MIT*.—The angular distributions of the absolute cross sections of protons scattered from thin natural indium targets have been measured. An incident beam of 7-Mev protons from the MIT-ONR electrostatic accelerator was used. The scattered protons were analyzed with a broad-range, uniform-field, magnetic spectrograph and were detected on nuclear-track plates. The elastically scattered protons, as well as those inelastically scattered to four levels in In^{115}, were observed. The four levels are at 1.982, 1.292, 1.335, and 1.078 Mev. Only the 1.292-Mev level has previously been reported. The absolute cross sections were determined by measurements on a weighed target and by relating the elastic yield at 7 Mev to the yield at lower energies where the predictions of Rutherford scattering are valid. The elastic distribution deviates form the Rutherford distribution. The inelastic distributions for the three lowest-energy states exhibit forward maxima, while the 1.982-Mev distribution is approximately isotropic. All levels have cross sections of the order of 0.1 mb per sterad. It appears likely that a direct interaction process enters into the formation of these states.

† This work has been supported in part by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.
* Now with Lockheed Aircraft Corporation.

THURSDAY MORNING AT 10:00

Sheraton Hall

(A. V. ASTIN presiding)

DA1. Problems in Meteor Physics. E. J. OPIK, *Armagh Observatory, Northern Ireland.* (30 min.)
DA2. Cosmic-Ray Evidence on the Origin of Meteorites. S. F. SINGER, *University of Maryland.*
DA3. Primary Helium in the Cosmic-Ray Spectrum. M. M. SHAPIRO, *U. S. Naval Research Laboratory.* (30 min.)
DA4. Solar Cosmic Rays and Their Propagation in Interplanetary Space. J. A. SIMPSON, *University of Chicago.* (30 min.)

THURSDAY AFTERNOON AT 2:00

Sheraton-Park, Continental Room

(D. M. VAN PATTER presiding)

Interactions of Light Nuclei

E1. Proton-Proton Scattering at 40 Mev.* DONALD A. SWENSON AND LAWRENCE H. JOHNSTON, *University of Minnesota.*—The differential proton-proton scattering cross section has been measured at 40 Mev using the Minnesota Proton Linear Accelerator. The scatterer is hydrogen gas at a pressure of one atmosphere. Two external large-scale detector telescopes are articulated to the scattering chamber by means of vacuum-tight ball-joints. One telescope covers the angular range from 4° to 20° (lab angle) with $\pm\frac{1}{2}°$ angular resolution. The other covers the angular range from 10° to 60° (lab angle) with $\pm 2°$ angular resolution. Protons are detected by a single thick NaI(Tl) crystal. The incident proton charge is collected in a Faraday cup. Preliminary data will be presented with 40 000 counts per point. The differential cross section goes through a minimum at 10° (lab angle) because of the Coulomb-nuclear interference, then rises by a factor of ten between 10° and 4°. A preliminary phase-shift analysis[1] indicates the necessity of including substantial $^3P_0$, $^3P_1$, and $^3P_2$ phase shifts in order to fit the data. A tensor component to the interaction is explicitly indicated by substantially different values for these three ^3P phase shifts.

* Supported in part by the U. S. Atomic Energy Commission.
[1] H. Pierre Noyes (private communications).

E2. Inelastic Reaction Cross Sections in NaI(Tl) Crystals.* LAWRENCE H. JOHNSTON AND DONALD A. SWENSON, *University of Minnesota.*—When a thick scintillation detector is used to count protons of homogeneous energy greater than 10 Mev (as in the above *P-P* scattering), an appreciable fraction of the protons make inelastic nuclear reactions in the scintillating material. This fraction produces substandard pulse heights in the detector output. Hence a monoergic beam of protons produces a pulse spectrum with a low pulse-height tail; so if pulse-height discrimination is used in counting protons, a correction is required to allow for the small pulses not counted. This correction was determined for protons of 40, 28, and 10 Mev by producing a $\frac{1}{8}$-in. wide beam of protons free from low-energy components and letting it strike the center of a $\frac{3}{4}$-in. wide NaI(Tl) crystal detector under conditions of negligible background. The "pure" beam was made by first collimating to 0.1 milliradian and magnetically analyzing to reject slit-scattered protons. The "tail" thus determined is most intense at low pulse heights, so the correction is quite insensitive to the discriminator setting between 70% and 100% of the elastic peak. The counting correction is +2.0% for 40-Mev protons, which indicates an inelastic cross section about $\frac{1}{3}$ of geometrical for sodium iodide.

* Supported in part by the U. S. Atomic Energy Commission.

E3. Observations of an Excited State in He^5 from the Scattering of 22-Mev Neutrons in He^4.* T. W. BONNER, F. W. PROSSER, JR., AND J. H. SLATTERY, *The Rice Institute.*—Using monoenergetic neutrons from The Rice Institute Van de Graaff accelerator and a He-filled ionization counter, a resonance has been found in He^5 at a laboratory neutron energy of 22.15 ± 0.13 Mev. This resonance corresponds to an excitation energy in He^5 of 16.72 ± 0.10 Mev, which is nearly the same as an excitation energy of 16.69 for the maximum in the $T(d,n)He^4$ cross section. It seems likely that the two resonances correspond to the same level in He^5. The neutron scattering experiments indicate that the level in He^5 has a width equal to or less than 120 kev, which width is much narrower than the ground state of He^5. Such a state in He^5 probably corresponds to a $\frac{3}{2}^+$ level made up of two neutrons and a proton in the *s* shell and one proton and one neutron in the *p* shell. Such a configuration would explain the large deuteron reduced width of the $T(d,n)He^4$ reaction and the small neutron width.

* Supported in part by the U. S. Atomic Energy Commission.

E4. Reaction $Li^6(\alpha,\gamma)B^{10}$.* S. S. HANNA AND LUISE MEYER-SCHÜTZMEISTER, *Argonne National Laboratory.*—The yield of gamma rays from the $Li^6(\alpha,\gamma)B^{10}$ reaction has been studied as a function of angle and bombarding energy from $E_\alpha=0.70$ Mev to 2.0 Mev. At the prominent resonance at $E_\alpha=1.18$ Mev ($E_{ex}=5.16$ Mev), the transitions are primarily through the first excited state at 0.72 Mev and the third excited state at 2.15 Mev in B^{10}. Angular distributions of the 4.44 and 3.01-Mev gamma rays are of the form $1+A_2\cos^2\theta$, with $A_2=-0.18\pm0.06$ and -0.22 ± 0.06, respectively. No evidence was obtained for capture into the state at $E_{ex}=5.11$ Mev, in agreement with the observation of other investigators.[1] The results will be discussed in terms of assignments to the energy levels of B^{10}.

* Work performed under the auspices of the U. S. Atomic Energy Commission.
[1] G. A. Jones and D. H. Wilkinson, Phil. Mag. 45, 703 (1954).

E5. Proton-Induced Reactions in Li^7 at 17.5 Mev.* D. R. MAXSON AND E. F. BENNETT, *Princeton University.*—Protons, deuterons, and tritons resulting from the bombardment of

Li^7 with 17.5 Mev protons have been observed at 21 angles from 8° to 150°. Particles of different Z/M were distinguished by using a proportional counter-scintillation counter telescope and recording coincidences on a two-dimensional pulse-height analyzer. The angular distribution of protons inelastically scattered from the 4.6-Mev level of Li^7 is substantially flat between 12° and 50° c.m., with a broad maximum at about 50°. At larger angles the cross section decreases monotonically by about a factor of 4 between 50° and 155° c.m. The intensity of protons from the 4.6-Mev level is much greater than that from the 7.5-Mev $\frac{3}{2}$-level, as is expected if both states belong to the p^3 configuration. Since the order of p^3 levels is known, the results justify a tentative assignment of $J=\frac{1}{2}$—for the 4.6-Mev level. The particles thus far identified include three groups of deuterons from the $Li^7(p,d)$ reactions leading to the ground, 2.2 Mev and 3.6-Mev states of Li^6. Deuteron angular distributions and shell model calculations of stripping ratios will be presented.

* This work was supported by the U. S. Atomic Energy Commission and the Higgins Scientific Trust Fund.

E6. Photodisintegration of Sodium by $Li^7(p,\gamma)$ Radiation. A. K. Mann,* T. R. Ophel, and I. F. Wright, *The Australian National University.*—A thin NaI(Tl) scintillator has been used as both source and detector of photoprotons produced in the sodium by $Li^7(p,\gamma)$ radiation. This technique, which also can be utilized with LiI and KI, and possibly with some organic scintillators, provides photoproton energy spectra of good resolution and high statistical precision. Spectra for sodium were obtained with both resonance and nonresonance radiation from the $Li^7(p,\gamma)$ reaction which permit identification of protons produced by the 14.8 and 17.6-Mev components of the incident radiation. On the basis of an energy calibration using protons from $B^{10}(d,p)$, four fully resolved and two incompletely resolved peaks appear to arise from absorption of the 17.6-Mev component and transitions to states in Ne^{22} at energies of 0, 1.3, 3.3, 4.4, and (5.4)(5.7) Mev. The spectrum due to the 14.8-Mev component is less certain, but preliminary results indicate absorption levels in Na^{22} at 14.2 and 14.9 Mev with transitions proceeding to the 1.3-Mev state of Ne^{22}.

* Fulbright Fellow 1955–1956, on leave from the University of Pennsylvania.

E7. $B^{11}(He^3,p)C^{13}$, and $B^{11}(He^3,d)C^{12}$ Angular Distributions at 4.5 Mev. H. D. Holmgren, E. A. Wolicki, and R. L. Johnston, *U. S. Naval Research Laboratory.*—The angular distributions of the ground-state proton group, first excited state proton group, and unresolved second and third excited state proton groups from the $B^{11}(He^3,p)C^{13}$ reaction have been measured for a bombarding energy of 4.5 Mev at 14 angles extending from 5° to 130°. The angular distribution of the deuteron group which leaves the C^{12} nucleus in the ground state has been measured at the same angles and bombarding energy. The angular distribution of the ground-state proton group appears to be peaked in both the forward and backward directions; however, the angular distributions of the other proton groups do not exhibit any strong variation with angle. The ground-state deuteron group is strongly peaked in the forward direction. Proton groups corresponding to higher excited states of C^{13} have also been observed, as well as the first excited deuteron group.

E8. Radiative Capture of Protons in Carbon from 80 to 126 kev.* W. A. S. Lamb and Ross E. Hester, *University of California, Livermore.*—An excitation curve has been measured for the reaction $C^{12}(p,\gamma)N^{13}$ in the energy interval 80 kev to 126 kev utilizing beam currents of 30 ma to 50 ma from the high current ion injector. The capture-gamma radiation was measured with a 4×4 in. NaI scintillator which was arranged to count only gamma radiation of the energy appropriate to the reaction. The yield per incident proton ranges from $7.0\pm2.3\times10^{-13}$ at 80 kev to $6.2\pm0.2\times10^{-16}$ at 126 kev with corresponding cross sections of $1.4\pm0.4\times10^{-11}$ barn and $6.8\pm0.8\times10^{-10}$ barn. A value for the cross section of the reaction $C^{12}(p,\gamma)N^{14}$ has been obtained at two energies; namely, $8.2\pm2.5\times10^{-9}$ barn at 126 kev and $5.1\pm2.0\times10^{-9}$ barn at 114 kev. The results are compared with previous measurements and with extrapolations from the resonance in this reaction at 456 kev using the Breit-Wigner single-level dispersion formula.

* Work performed under the auspices of the U. S. Atomic Energy Commission.

E9. Angular Distributions of Protons from the $Be^9(He^3,p)B^{11}$ and $C^{13}(He^3,p)N^{15}$ Reactions. R. L. Johnston, H. D Holmgren, and E. A. Wolicki, *Naval Research Laboratory.*—Angular distributions have been measured at a bombarding energy of 4.5 Mev at 14 angles ranging from 5° to 135° for several groups of protons from the $Be^9(He^3,p)B^{11}$ and $C^{13}(He^3,p)N^{15}$ reactions. Measurements have been made on the proton groups from the $Be^9(He^3,p)B^{11}$ reaction which leave the residual nucleus B^{11} in states of 4.46 and 5.03 Mev of excitation. The angular distributions of these two groups have a strong maximum in the forward direction. The second excited state group has a secondary peak in the region of 50° and a minimum about 105° in the center-of-mass system. The third excited state group has a secondary peak near 60° with a minimum about 100°. The positions of the maxima and minima in these angular distributions show a correspondence with the maxima and minima of the ground state and first excited state angular distributions.[1] Measurements have been made on the proton groups from the $C^{13}(He^3,p)N^{15}$ reaction which leave N^{15} in the 5.28, 5.31, and 6.33-Mev excited states. The proton groups to the 5.28 and 5.31-Mev states are not resolved, and the composite angular distribution will be given.

[1] Wolicki, Holmgren, Johnston, and Geer, Bull. Am. Phys. Soc. Ser. II, 1, 325 (1956).

E10. Gamma Transitions from the 15.1-Mev Level in Carbon-12. C. N. Waddell, H. E. Adelson, B. J. Moyer, and H. C. Shaw, *University of California, Berkeley.**—The relative probability of transitions from the 15.1-Mev level in C^{12} to the ground and first excited state has been measured as ~10% with a 180° magnetic pair spectrometer by bombarding carbon with 31-Mev protons. A gamma ray of 12.8±0.2 Mev was also observed with an intensity comparable to that of the 10.7-Mev gamma ray. The yield of 15.1-Mev gamma rays in the bombardment of carbon by protons was measured from threshold to 340 Mev. In attempting to test the validity of the assignment of $T=1$ to the level, we examined the following reactions allowed by the I-spin selection rules: $C^{12}(p,p')C^{12*}$, $C^{12}(n,n')C^{12*}$, $B^{11}(d,n)C^{12*}$, and $Be^9(\alpha,n)C^{12*}$. In each case we observed a yield of 15-Mev gamma rays. In addition we examined $C^{12}(\alpha,\alpha')C^{12*}$, and $C^{13}(d,d')C^{13*}$, which forbid the formation of $T=1$ state. Here we found no observable yield until the energies of the incoming particles were sufficiently high so that one would expect breakup of the outgoing alpha or deuteron.

* This work was done under the auspices of the U. S. Atomic Energy Commission.

E11. Reactions $C^{13}(\alpha,p)N^{16}$ and $B^{10}(\alpha,p)C^{13}$ at 30.5 Mev.* C. E. Hunting and N. S. Wall, *MIT.*—The reactions $C^{13}(\alpha,p)N^{16}$ and $B^{10}(\alpha,p)C^{13}$ have been investigated using the ~30.5-Mev α-particle beam of the MIT. cyclotron. The ground-state angular distribution from 5° to 142° (c.m.) of protons from $C^{13}(\alpha,p)N^{16}$ is very similar to the data of Sherr and Rickey at ~30 Mev[1] and at 41.5 Mev,[2] with pronounced maxima at 0°, 42°, 87°, and 133° and minima at 23°, 66°, and 113°. For the reaction $B^{10}(\alpha,p)C^{13}$ a target prepared from 97% enriched B^{10} was employed[3]; the main feature in the observed

angular range, from 44° to 167° (c.m.), is the predominantly forward nature of the angular distribution of the ground-state protons, the differential cross section at 44° being approximately three times that at 118°. A comparison with the predictions of the stripping model[4] will be presented.

* This work was supported by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.
[1] R. Sherr (private communication).
[2] R. Sherr and M. Rickey, Bull. Am. Phys. Soc. Ser. II, **2**, 29 (1957).
[3] Supplied by the Stable Isotope Division, Oak Ridge National Laboratory.
[4] S. T. Butler, "Direct nuclear reactions" (to be published).

E12. Correspondence of the $N^{14}(d,\alpha)C^{12*}$ and the $C^{12}(\alpha\alpha')C^{12*}$ Reactions.† G. E. Fischer and V. K. Fischer, *Columbia University and Brookhaven National Laboratory.*—The angular distributions of alpha particles from the reactions leading to the ground, first (4.4 Mev) and third (9.6 Mev) states of C^{12}, have been measured for an incident deuteron energy of 20.9 Mev. The work was carried out at the Brookhaven 60-in. cyclotron with scattering equipment previously described.[1] The angular resolution of the dE/dx *vs* E counter telescope was ±1° in the laboratory system. The gas targets were filled with nitrogen of natural isotopic abundance and 99.9% chemical purity. The angular distribution of elastically scattered deuterons was also determined. The absolute cross sections for the (d,α) reactions mentioned above vary respectively between 0.2–0.02, 0.9–0.1, and 0.2–0.02 mb/sterad. Alpha particles going to the second excited state of carbon (7.6 Mev) were seen, but because of the very small cross section for this mode (approximately 0.02 mb/sterad), the angular data is unreliable. A comparison of the (d,α) data and the $C^{12}(\alpha\alpha')C^{12}$ angular distribution[2] obtained at an almost corresponding excitation energy will be made.

† This work was partially supported by the U. S. Atomic Energy Commission.
[1] V. K. Fischer, Bull. Am. Phys. Soc. Ser. II, **2**, 28 (1957).
[2] M. J. Walters, Phys. Rev. **103**, 1763 (1956).

E13. $N^{15}(p,n)O^{15}$ Threshold Energy.* L. Lidofsky, J. Weil, and K. Jones, *Columbia University.*—A precision measurement of the $N^{15}(p,n)O^{15}$ threshold energy has been made in terms of the $Li^7(p,n)Be^7$ threshold energy.[1] The precision was made possible by use of the following facts: (a) the $N^{15}(p,n)O^{15}$ threshold energy (3.776 Mev)[2] is approximately twice that of $Li^7(p,n)Be^7$ (1.8811 Mev)[1]; and (b) for the same accelerating voltage, the energy per proton in an H^+ beam is approximately twice that in an HH^+ beam. The H^+ beam was brought out of the 90° port of the Van de Graaff deflecting magnet and bombarded a $Pb(N^{15}O_3)_2$ target. Simultaneously, the HH^+ beam was brought out of the 60° port and bombarded a Li target. The energy difference between the $N^{15}H^+$ threshold and the Li^7HH^+ threshold was measured in terms of the small (~0.25%) change in magnetic field needed to cover the energy interval. A preliminary value for the energy difference is 17.6±1.0 kev, leading to a threshold energy for $N^{15}(p,n)O^{15}$ of 3.7808±0.0015 Mev.

* This work was partially supported by the U. S. Atomic Energy Commission.
[1] Jones, Douglas, McEllistrom, and Richards, Phys. Rev. **94**, 947 (1954).
[2] Kington, Bair, Cohn, and Willard, Phys. Rev. **99**, 1393 (1955).

E14. Angular Distributions of Protons in the $F^{19}(\alpha,p)Ne^{22}$ Reaction. G. F. Pieper and N. P. Heydenburg, *DTM, Carnegie Institution of Washington.*—Angular distributions of protons corresponding to the ground state and first excited-state transtions in $F^{19}(\alpha,p)Ne^{22}$ have been obtained at five bombarding energies between 6.0 and 6.55 Mev. At some energies the distributions have strong forward peaks similar to those expected from a direct interaction mechanism; however, the rapid variation of distribution shape with energy and the resonant nature of the excitation function indicate strong contributions from compound nucleus processes. A measurement of the angular correlation between protons to the first excited state and the 1.28-Mev de-excitation gamma rays is in progress to investigate further possible direct effects in the reaction mechanism.[1]

[1] G. R. Satcheler, Proc. Phys. Soc. (London) **A68**, 1037 (1955).

E15. $F^{19}(\alpha,n)Na^{22}$ Reaction.* R. M. Williamson and B. S. Burton, *Duke University.*—Neutrons from alpha bombardment of fluorine have been detected by three different neutron energy sensitive counting arrangements: (1) a slightly moderated BF_3 counter; (2) a Li^6I scintillator; (3) a sulfur absorber plus a "flat" BF_3 counter. The range of alpha energies was 2 to 3.9 Mev. The first slow neutron yield was observed at a 2.504 Mev resonance having a 9-kev width and a cross section of about 0.5 mb. The higher energy resonances had similar widths and about 100-kev spacings. The small yield between resonances was difficult to estimate because of contaminant $C^{12}(\alpha,n)$ neutrons. Methods (1) and (2) were used to find approximate slow neutron energies. The 111-kev sulfur resonance was then observed using neutrons from the first F^{19} resonance. The neutron energy was varied by changing the absorber and counter angle. The low neutron yield necessitated poor angular resolution. The $F^{19}(\alpha,n)$ ground state Q was −1.950±0.015 Mev. Method (1) indicated no new slow neutron groups below an alpha energy of 3.12 Mev. Above this energy, both slow neutrons and 602-kev gammas were observed. The gammas were found to be isotropic at two resonances. These data support the assumption of a 602-kev, $J=0$ level in Na^{22}. Resonances in the $F^{19}(\alpha,p\gamma)Ne^{22*}$ (1.277 Mev) gamma yield were observed and compared with those in the neutron yield.

* Supported by the U. S. Atomic Energy Commission.

Thursday Afternoon at 2:00

Sheraton-Park, Caribar-Mural Room

(E. Ambler presiding)

Cryogenics

F1. Transition to Superconductivity of Contacts between Copper-Plated Tin Wires.* Hans Meissner, *The Johns Hopkins University.*—The contact resistance between crossed copper plated tin wires has been measured as a function of the current at various temperatures around the transition temperature of tin. It has been found that up to copper thickness of 5000 A the contacts become superconducting at sufficiently low currents and temperatures. No systematic difference was observed when only one rather than both of the wires was plated. Most of the contacts were stable enough so that a "diagram of state" could be established, that is, a diagram of lines of constant R/R_n in the I-T plane. R is the contact resistance at certain values of current I and temperature T, and R_n its value just above the transition temperature of tin.

The line $R/R_n=0$ gives the I_c-T curve. This curve differs from the H_c-T curve of bulk superconductors in that it has zero slope at the critical temperature. This is in qualitative agreement with the relation of critical current *vs* temperature for very thin wires. It was found that the temperature at which I_c drops to 1/100 of its value at 2.65°K is around 3.5°K, independent of the copper thickness as long as the contacts still became superconducting.

* Work performed under Contract of the Office of Naval Research.

F2. Superconductivity at Millimeter Wave Frequencies.* GILBERT S. BLEVINS, WALTER GORDY, AND WILLIAM M. FAIRBANK, *Duke University.*—The development at Duke University of refined millimeter wave techniques for the 0.5 to 5 mm region made possible investigations of the temperature dependence of the surface resistance of superconducting tin in the frequency region where $h\nu \gtrsim kT$. In the first experiments[1] the onset of superconductivity, as evidenced by a noticeable change in the high-frequency surface resistance, was found to depend on the frequency. These measurements have been extended to different types of surfaces. More sensitive methods have been developed for ascertaining small changes in resistance near the transition temperature. A new cryostat and microwave system has been constructed which makes possible a significant extension of the measurements to frequencies above 150 kMc/sec. In both plated surfaces and surfaces made from the bulk metal, the transition temperature was found to shift to lower temperatures as the frequency was increased above 50 kMc/sec in agreement with the earlier measurements.[1] However, the amount of the shift was found to be less in the bulk metal surface than in the plated surface. It possibly depends on the width of the intermediate state.

* Supported by the Office of Ordnance Research, U. S. Army and the Office of Scientific Research, U. S. Air Force.
[1] Blevins, Gordy, and Fairbank, Phys. Rev. **100**, 1215 (1955).

F3. Viscosity of Liquid Helium. BENJAMIN WELBER, *Lewis Laboratory, NACA.*—The product of the viscosity η and the density ρ of liquid helium has been measured by a method employing a piezoelectric crystal immersed in the fluid. The crystal, in the form of a right circular cylinder, is excited into a steady state of torsional vibration at its resonant frequency, and the quantity $\Delta=W'^d/2W'^v$ (W'^d=energy dissipated per cycle, W'^v=vibrational energy) is determined from the electrical measurements, over the temperature range 1.3°K–4.2°K. $\eta\rho$ is then proportional to $(\Delta-\Delta_0)^2$ where Δ_0 is the value of Δ in vacuum. For the crystal employed in the measurements Δ_0 corresponds to a Q of about 1.3×10^7 and is only about 1.2% of the value of Δ at 4.2°K. The measurements show a high degree of reproducibility and are practically independent of amplitude. Preliminary measurements in the neighborhood of the λ point are sufficiently well resolved to show that η increases by more than 0.1η in the range of 2.18°K to 2.19°K.

F4. Transport Properties of He II in Fine Channels.* A. H. SPEES, J. REPPY,† J. BURNHAM, AND C. A. REYNOLDS, *University of Connecticut.*—The heat transport by He II through 0.1 μ channels was measured in apparatus having packed rouge columns of different cross sections. The normal fluid viscosity was calculated from the heat transport extrapolated to zero powers. A comparison was made with oscillating disk and rotating cylinder measurements. In contrast to the latter our results down to 1.35°K show no rise in viscosity. This behavior agrees with results from larger channels between optical disks.[1] An observed critical velocity of about 0.1 cm/sec in the normal fluid agrees with rotating cylinder data.[2] Close to the λ point the heat transport was found to decrease. A lowering of the λ-point temperature was observed with increasing heat currents, a result that can be ascribed to an accompanying increase in fountain effect pressure.

* Supported by the Office of Naval Research and grants from Sigma Xi-RESA research fund.
† Now at Yale University.
[1] Van Groenou, Poll, Delsing, and Gorter, Physica **22**, 905 (1956).
[2] W. J. Heikkila and A. C. Hollis-Hallett, Can. J. Phys. **33**, 420 (1955).

F5. Specific Heat of Liquid He⁴ near the λ Point.* W. M FAIRBANK, M. J. BUCKINGHAM, AND C. F. KELLERS, *Duke University.*—The specific heat of liquid helium under its saturated vapor pressure has been measured in the neighborhood of the λ point with a resolution of a few microdegrees. The results indicate that at the λ point the specific heat has both a logarithmic singularity and a discontinuity. To within closer than 10^{-8} deg on both sides of the λ point, the results for the specific heat per mole, C_{vp}, can be represented by $C_{vp}/R=7.1f(t)\ln(4.6/t-1)-2.5\Delta(t)$ per mole, where $t=T/T_\lambda$, $\Delta(t)=0(t<1)$, $\Delta(t)=1(t>1)$ and $f(t)$ is a smooth function of (t) taking the value unity at $t=1$. The apparatus was so constructed that the liquid helium was everywhere within 0.003 in. of the copper container. Thermal equilibrium was achieved by means of the copper and did not depend on the high thermal conductivity of superfluid helium. Measurements were made at several heating and cooling rates through the λ point in both directions.

* Supported in part by the National Science Foundation and the Ordnance Corps, Department of the Army.

F6. Theory of Inelastic Scattering of Cold Neutrons from Liquid Helium. MICHAEL COHEN AND RICHARD P. FEYNMAN, *California Institute of Technology.*—A measurement of the energy losses of monoenergetic neutrons scattered from liquid He II would permit a determination of the energy-*vs*-momentum relation for the elementary excitations (phonons and rotons) in the liquid. A major part of the scattering at a fixed angle arises from production or annihilation of a single excitation and appears as sharp lines in the energy spectrum. From the position of these lines the energy-*vs*-momentum relation of the excitations can be inferred. Other processes, such as production or annihilation of multiple excitations, contribute a continuous background, and occur at a negligible rate if the incident neutrons are slow ($\lambda\geq4A$) and the helium cold ($T<2$°K). The total cross-section data[1] can be accounted for by production of single excitations; the theoretical cross section, computed from a wave function previously proposed to represent excitations,[2] agrees with experiment over the entire energy range, within 30%. Line widths in the discrete spectrum are negligible at 1°K because of the long lifetime of phonons and rotons.

[1] Sommers, Dash, and Goldstein, Phys. Rev. **97**, 855 (1955).
[2] R. P. Feynman and M. Cohen, Phys. Rev. **102**, 1189 (1956).

F7. Nuclear Spin Alignment in Solid He³.* G. K. WALTERS† AND WILLIAM M. FAIRBANK, *Duke University.*—Nuclear resonance techniques, previously used by us[1] to demonstrate nuclear antiparallel alignment in liquid He³ below 1°K, have been extended to solid He³. Preliminary measurements indicate that there is no nuclear antiparallel alignment in solid He³ down to 0.2°K. Since these measurements indicate that at 0.2°K the nuclear spins are considerably more ordered in liquid He³ than in the solid, one would expect the entropy of solid He³ to be greater than the entropy of the liquid. This has been confirmed by removing the pressure on solid He³ at 0.2°K and allowing the solid to expand into a liquid. A rise in temperature is observed when the solid changes into a liquid adiabatically. At 1.2°K the same experiment produces cooling. Adiabatic compression of liquid He³ to solid He³ at 0.2°K should result in cooling as first predicted by Pomeranchuk.[2] We are investigating this method of cooling. The spin lattice relaxation time has been measured in solid He³ and is the order of seconds. This is considerably less than the spin

lattice relaxation time in liquid He^3, indicating that the He^3 atoms have considerable relative motion in the solid. The drop in the relaxation time helped to identify the solid from the liquid.

* This project has been supported by contracts with the Ordnance Corps, Department of the Army.
† Postdoctoral National Science Foundation Fellow.
[1] Fairbank, Ard, and Walters, Phys. Rev. **95**, 566 (1954).
[2] I. Pomeranchuk, J. Exptl. Theoret. Phys. (U.S.S.R.) **20**, 919 (1950).

F8. Adiabatic Demagnetization of Chromic Methylammonium Alum and the Temperature Scale below 1°K. E. Ambler and R. P. Hudson, *National Bureau of Standards.*—We have determined the entropy-temperature relation for chromic methylammonium alum over the range 0.015°–1.0°K by adiabatic demagnetization and gamma-ray heating. Errors were minimized by achieving small background heating, by careful calibration of the "heater," and by extending direct Q-S determinations (necessary for the lowest temperatures) up to a temperature well within the region of good thermal diffusivity, wherein pseudo specific heat $C^*(=dQ/dT^*)$ determinations are reliable. The latter were shown to be trustworthy, in fact, down to 0.06°K. Direct evidence of good uniformity of temperature throughout the sample, even after prolonged heating, was obtained for $T>0.06$°K. The estimated accuracy for T is $\pm 6\%$ throughout the entire region. We conclude that, within these limits, the S-T relation obtained is *generally* valid down to 0.06°K; below this point the well-known variability of the S-T^* relation for different specimens tempers one's optimism. The data conform very well with the Hebb-Purcell theory for $T>0.08$°K. The value found for the critical temperature, T_o, is 0.016°K (compare 0.02°K obtained by Gardner and Kurti[1]).

[1] W. E. Gardner and N. Kurti, Proc. Roy. Soc. (London) **A223**, 542 (1954).

F9. Oscillating Hall Effect and Magnetoresistance of a Gallium Single Crystal at Helium Temperatures.* J. Yahia and J. A. Marcus, *Northwestern University.*—Measurements were made on a crystal (residual resistance ratio 1.0×10^{-3}) in the shape of a thin strip grown by Fultyn's[1] method. The a axis was parallel to the length and the c axis perpendicular to the face. At 280°K the average Hall coefficient is -12.4×10^{-4} emu, at 77°K it is -10.7×10^{-4} emu, and at 4.2°K it is -10.6×10^{-3} emu. Rotation curves were obtained at each temperature by rotation of the magnetic field in a plane perpendicular to the a axis. The maximum Hall voltage was found when the magnetic field was displaced 22° from the c axis at room temperature and 42° at nitrogen temperatures. (There was no displacement at 4.2°K.) Oscillations, periodic in $1/H$, were observed to be $\simeq$180° out of phase in the Hall coefficient and magnetoresistance at 1.49°K and 10 kilogauss. The period of these oscillations is $\simeq 50\times10^{-7}$ gauss^{-1}, in agreement with Shoenberg's[2] results on the de Haas-van Alphen effect in gallium single crystals. The amplitude of the Hall coefficient oscillations increases by a factor of 4 from 4.2°K to 1.36°K (where it is 1% of the average coefficient). Further work is in progress on crystals of different orientation.

* Supported by the National Science Foundation.
[1] R. V. Fultyn, M. S. thesis, Northwestern University (1955).
[2] D. Shoenberg, Trans. Roy. Soc. (London) **245**, 1–57 (1952).

F10. Studies of the Low-Temperature Magnetization of Cerium Salts Using the Faraday Effect. P. B. Alers, *U. S. Naval Research Laboratory.*—The magnetization of various cerium compounds at liquid helium temperatures has been observed by means of the Faraday effect. Fields ranging to 60 kilogauss were used. Observations have been made on cerous oxide in a glass matrix, cerous nitrate dissolved in glycerol, and cerous nitrate dissolved in water. The magnetization isotherms, when plotted as a function of H/T, do not quite superpose. The data can, however, be fitted to a Brillouin function using $J_e=\frac{1}{2}$ and g values ranging from 1.6 to 1.8, depending on the substance and solvent. The work of Henry,[1] using another technique, indicates that cerous nitrate hexahydrate, in the form of a crystalline powder, exhibits nearly ideal behavior ($g=2.1$). It thus appears that the cerium ions show stronger interactions in solution than in the crystalline state.

[1] W. E. Henry, Phys. Rev. **95**, 603(A) (1954).

F11. Thermal and Magnetic Properties of Cerium Ethyl Sulfate between 0.02°K and 1.5°K. C. E. Johnson and Horst Meyer, *Oxford University* (introduced by A. H. Cooke).—Demagnetization experiments have been carried out on a spherical single crystal of cerium ethyl sulfate and measurements have been made of the adiabatic differential susceptibility in small fields up to 650 gauss applied along the crystal axis. The Curie point (0.05°K) is reached by removing about one third of the electronic entropy, and since the entropy may be almost completely extracted with the fields available this salt is particularly suitable for investigating the region in which cooperative effects occur at very low temperatures. The absolute temperature scale was established down to 0.02°K; below the Curie point where the magnetic temperature varies very slowly this was done by constructing a $Q-S$ curve and using the relation $T=dQ/dS$. Adiabatic magnetization below the Curie point produced a lowering of temperature characteristic of antiferromagnetic ordering. The maximum cooling observed was about 20 mdeg. A comparison of the specific heat, susceptibility and magnetization curves with those predicted by a theoretical model is given.

F12. Magnetic Measurements on Cerium Magnesium Nitrate below 0.01°K.* R. C. Sapp, *The Rice Institute.*—Thermal and magnetic properties of cerium magnesium nitrate cooled below 1°K by adiabatic demagnetization indicate the onset of cooperative ordering in the millidegree-range[1] due to dipole-dipole interaction, which accounts for almost all of the magnetic specific heat[2] since there are no Stark or hyperfine splittings. The ballistic adiabatic susceptibility in zero field of a single crystal specimen, observed by switching on a primary field of several gauss in a mutual inductance bridge circuit, increases continuously with decreasing entropy down to the lowest entropy attained ($S=0.32R$), when measured parallel to the crystallographic trigonal axis; when measured perpendicular to the axis, it becomes constant below $S=0.38R$. The magnitude of the parallel susceptibility is considerably smaller than that computed from the perpendicular susceptibility and the magnetic anisotropy of the cerium ions ($g_\perp=7.4g_\parallel$)[2]. Magnetization curves at the lowest entropy have been deduced from the dependence of these susceptibilities on applied external fields up to 300 gauss. No remanence was noted under any of the experimental conditions.

* Assisted by grants from the Robert A. Welch Foundation.
[1] J. M. Daniels and F. N. H. Robinson, Phil. Mag. **44**, 630 (1953).
[2] Cooke, Duffus, and Wolf, Phil. Mag. **44**, 623 (1953).

F13. Paramagnetic Relaxation in $CuNa(UO_2)_3(C_2H_3O_2)_9\cdot 9H_2O$ and $Mn(NH_4)_2(SO_4)_2\cdot 6H_2O$ at 1 Mc and Liquid Helium Temperatures. L. D. Roberts, J. W. T. Dabbs, and H. Postma, *Oak Ridge National Laboratory.*—The magnetic susceptibilities of copper sodium uranyl acetate and of manganous ammonium sulfate have been measured at a frequency of 1 Mc by means of a heterodyne beat method. The measurements were made as a function of temperature in the liquid helium region and of magnetic field up to 400 oe. In this temperature region the spin specific heat of these salts is given in good approximation as b/T^2 where b is a constant and T is the absolute temperature. For the manganese salt we obtained $b/R=0.0303$ and for the copper salt $b/c=(3.25\pm0.2)\times10^4$ where R is the gas constant and c the Curie

constant. The powder Curie constant for the copper salt was measured as 0.512 ± 0.01 by a Hartshorn bridge technique at 1000 cps. Thus for the copper salt, a value of $b/R = 2.00 \times 10^{-4}$ is obtained. This may be compared with the contribution of 1.2×10^{-4} due to hyperfine structure coupling in the Cu^{++} ion.

F14. Magnetic Susceptibility of $NpO_2Rb(NO_3)_2$ at Liquid Helium Temperatures. J. W. T. Dabbs, L. D. Roberts, and G. W. Parker, *Oak Ridge National Laboratory.*—In connection with nuclear orientation experiments on Np^{237} nuclei, it was necessary to determine the magnetic susceptibility of $NpO_2Rb(NO_3)_2$ at low temperatures. Measurements of the susceptibility of a 7.8-g powder sample and the susceptibility of a 3.3-g single crystal parallel to the c axis have been made at temperatures between 1.2°K and 4.2°K, using a Hartshorn mutual inductance bridge.[1] The susceptibilities were found to follow a Curie-Weiss law. The value of $g_{\parallel}^2 + 2g_{\perp}^2$ was 11.25 ± 0.10 from the powder measurement, and the $g_{\parallel}$ value obtained in the single crystal measurement was 3.45 ± 0.07. In each measurement only small Weiss constants of about 0.03–0.04°K were found. The powder results are slightly lower than those from microwave measurements[2] made at 20°K.

[1] Erickson, Roberts, and Dabbs, Rev. Sci. Instr. **25**, 1178 (1954).
[2] Bleaney, Llewellyn, Pryce, and Hall, Phil. Mag. **45**, 992 (1954) and P. M. Llewellyn, thesis, Oxford, 1955 (unpublished).

Invited Paper

F13. Superconducting Properties of Thin Filaments. O. S. Lutes, *National Bureau of Standards and Minneapolis-Honeywell Company.* (30 min.)

Thursday Afternoon at 2:00

NBS, East Building

(J. H. Schulman presiding)

Solid-State Physics II. Mostly Nonmetals

FA1. Surface Semiconduction in ZnO. D. G. Thomas and J. J. Lander, *Bell Telephone Laboratories, Inc.*—If small (diam <0.003 in.) single crystals of ZnO of low conductivity [<0.05 (ohm cm)$^{-1}$] are exposed at 20–300°C to zinc vapor, the conductivity of the crystals may be increased by a factor of 10 or more. This increase must be a surface effect since the bulk diffusion rate and solubility are negligibly small, and because at saturation a surface conductivity of about 1.5×10^{-4} mhos/square is produced independent of crystal diameter. The surface conductivity persists to very low zinc relative pressures. By quenching the adsorbed zinc may be "frozen" on the surface and then at high coverages the conductivity remains unchanged to 4.2°K, but at lower coverages the conductivity falls as the temperature falls. At 250°C hydrogen produces effects similar to those of zinc, but zinc is probably formed by surface reduction. However, cesium is adsorbed and produces surface conduction. The ad-atoms do not form a metallic layer but act as donors to form an enrichment space charge layer. At higher coverages an impurity band may be important in this layer.

FA2. Impurity-Controlled Electronic Properties of Magnesium Oxide.* John E. Wertz, Juana L. Vivo Acrivos, and Peteris Auzins, *University of Minnesota.*—The large energy gap between the valence and conduction bands in MgO crystals causes impurities to play a controlling role in determining such electronic properties as the absorption spectrum, electrical- and photoconductivity and the luminescence behavior. It is extremely difficult to prepare crystals which do not contain transition elements in amounts which are readily detectable by their electron spin resonance absorption. Of those commonly present, iron and chromium are probably the most important, though manganese and vanadium often play a role. Their ability to exist in either of two stable valence states insures the presence of numerous filled or empty levels in the energy gap. Valence changes are readily detected after such treatments as heating in vacuum, in oxygen or magnesium vapors or ultraviolet or x-irradiation. After some of these an apparently stable state is reached, while especially for radiation, numerous changes occur in decay processes. The pattern of electron transfer among the several impurities serves as a guide to locate relatively the energy levels. In some processes one merely requires a redistribution of the existing positive ion vacancies, while in others they are formed or destroyed. Identification of the spectrum of Cr(+3) with an associated vacancy has permitted the observation of changes in association.

* This research was supported in part by the U. S. Air Force through the Air Force Office of Scientific Research.

FA3. Indirect Transitions at the Center of the Brillouin Zone in InSb.* William P. Dumke, *Chicago Midway Laboratories.*—The theory of indirect optical transitions is extended to the case where valence and conduction and extrema occur at the center of the Brillouin zone. For this case, the intermediate virtual state as well as the final state are in the conduction band and the electron gains an appreciable energy when it is scattered between these states by the absorption of an optical mode phonon. Because of screening effects and the possible breakdown of perturbation theory, the usual long wavelength polar interaction was assumed to be independent of phonon wave number. We found that the above theory was in close agreement with the absorption edge data on InSb over a reasonable range of temperatures. This model is consistent with the various experiments on InSb and in particular it is consistent with the pressure experiment of Keyes if there are degenerate valence bands, which also would appear to be required by the symmetry of the f sum rule. This proposed indirect transition process in InSb suggests the possibility of modulating the absorption constant below the threshold for direct transitions by the selective production of long wavelength optical mode phonons. These might be emitted by electrons excited by pulsed electric fields.

* This research was supported by the U. S. Air Force, through the Office of Scientific Research of the Air Research and Development Command.

FA4. Thermal Conductivity of PbTe Doped with *P*-Type, *N*-Type, and Electrically Inert Solutes. W. V. Huck, R. W.

FRITTS, AND S. KARRER, *Milwaukee Gas Specialty Company.*—A simple relaxation method has been used to measure thermal conductivity of cylindrical ingots of doped PbTe. This method yields an accuracy of ±5% for such semiconducting materials and can be used for polycrystals and single crystals that are isotropic. Ingots, having a wide range of *N*-type or *P*-type conductivity, were prepared by doping with Bi_2Te_3 and Na_2Te, respectively. The thermal conductivity of both *N*-type and *P*-type PbTe increases with electrical conductivity as $\Delta K/\Delta\sigma = 3\times10^{-6}$ w-ohm/°C over the nondegenerate range. This figure is approximately ⅓ of the theoretical Wiedemann Franz ratio for nondegenerate electronic systems and is to be expected since the donor or acceptor defects reduce lattice phonon transfer while increasing the electronic contribution. Soluble species which are electrically inert, for example, PbSe and SnTe, cause reduction in the thermal conductivity of the resulting solid solution by increasing phonon scattering.

FA5. Effect of Fast Neutron and Gamma-Ray Bombardment on the Low-Temperature Thermal Conductivity of Nonmetals.* A. FONER COHEN AND L. C. TEMPLETON, *Oak Ridge National Laboratory.*—Measurements by Berman[1] on the low-temperature thermal conductivity of fast neutron bombarded SiO_2 indicate that this property is effective for studying radiation effects in nonmetals. Measurements of the conductivity $\mathfrak{K}$ on single crystals of MgO, KCl, LiF, CaF_2, SiO_2, and Ge before and after irradiation have been made. The range of measurement is from 2.5°K to 22°K and in some cases to 80°K. Both fast neutrons and Co^{60} gamma rays have been used. For SiO_2, CaF_2, and KCl following room temperature Co^{60} gamma irradiation, $\mathfrak{K}$ decreased over the entire range of measurement. After fast neutron bombardment in the graphite reactor at room temperature, $\mathfrak{K}$ of MgO, KCl, Ge, SiO_2 and LiF decreased markedly in the region of maximum conductivity and also below the maximum in the boundary scattering range. Measurements as a function of neutron and gamma dose made on KCl will be discussed. It has been found that for a cleaved, unannealed KCl crystal $\mathfrak{K}$ increases over the range of measurement after gamma irradiation, suggesting that the defects produced by the photons release the residual strains in some manner.

* This work is sponsored by the U. S. Atomic Energy Commission.
[1] R. Berman, Advances in Phys. **2**, 103 (1953).

FA6. Time Constants in Photoconductive Cells. Z. SZEPESI, *Canadian Marconi Company* (introduced by D. A. Anderson).—Decay and rise curves for cadmium sulfide and cadmium selenide photoconductors have been analyzed. An attempt has been made to find relations between the decay and rise time constants and more fundamental characteristics which play a part in the description of the photoconductive mechanism. Thus the following relations were found: the decay time constant $\tau_d = \tau_c + \tau_{trap}$; the rise time constant $\tau_r = \tau_c + \tau_{trap} + \tau_{red}$; where τ_c is the lifetime of the free electrons in the conduction band, τ_{trap} is the emptying or filling time of the traps, and τ_{red} is the redistribution time of the different classes of recombination centers.

FA7. Attainment of a Vacancy Excess in NaCl by Quenching. JARUS W. QUINN, *RIAS.*—Cunnell and Schneider[1] have variously reported that quenching an NaCl crystal from 730°C to room temperature leads to no change or to a decrease in the electric conductivity. This implies that no appreciable number of free vacancies were frozen in.[2] However, Ewles and Stead[3] reported a threefold increase in the electrolytic conductivity below 500°C when an NaCl crystal was quenched from 800°C. In our work several Harshaw NaCl crystals 1×1×0.1 cm in size were provided with chemically deposited silver electrodes, heated to 500°C and slowly cooled to room temperature. The dc conductivity σ_I of each crystal was then measured while it was slowly heated to 500°C. It was then rapidly quenched to room temperature and its conductivity σ_{II} measured again as a function of temperature. σ_{II}/σ_I equals three at 200°C and decreases steadily with increasing temperatures, approaching one at 400°C.

[1] F. A. Cunnell, Ph.D. thesis, University of Durham (1951); F. A. Cunnell and E. E. Schneider, Phys. Rev. **95**, 598(A) (1954).
[2] F. Seitz, Revs. Modern Phys. **26**, 13, (1954).
[3] J. Ewles and J. C. Stead, Proc. Phys. Soc. (London) **B69**, 396 (1956).

FA8. Photoproduction of V_1 Centers in KBr Crystals.* G. CHIAROTTI AND N. INCHAUSPE, *University of Illinois.*—V_1 centers have been observed so far as a result of the irradiation of alkali-halide crystals with x-rays or β rays at low temperatures. Thermal destruction of V_1 centers in KBr occurs at about −156°C and is accompanied by a release of electric charges.[1] In the present experiments, Harshaw KBr crystals were irradiated for times ranging from several minutes to a few hours with monochromatic light of wavelength 190 mμ which is absorbed in the tail of the fundamental band. The intensity of the incident light was about 10^{12} photons per sec per cm^2. During the warmup following irradiation, only one burst of current was observed, at a temperature which corresponds to the destruction of V_1 centers. Optical absorption measurements failed to detect the V_1 band, setting an upper limit for the concentration of V_1 centers of 10^{14} cm^{-3}.

* Supported by the Office of Naval Research and Office of Scientific Research.
[1] D. Dutton and R. Maurer, Phys. Rev. **90**, 126 (1953).

FA9. Hyperfine Interactions in *F* Centers.* G. J. WOLGA AND M. W. P. STRANDBERG, *MIT.*—A program of investigation of *F* centers in alkali-halide crystals under high resolution conditions is described. Use of a very high sensitivity spectrometer capable of detecting 6×10-in. spins makes possible the investigation of crystals with low radiation damage. It is to be expected that with minimized radiation damage the hyperfine splitting of the *F*-center resonance due to both nearest and next nearest neighbor nuclei can be resolved. Data are presented showing such next nearest neighbor splittings in NaF. It is felt that such techniques supply a valuable approach to an understanding of radiation damage in crystals.

* This work was supported in part by the Army (Signal Corps), the Air Force (Office of Scientific Research, Air Research and Development Command), and the Navy (Office of Naval Research).

FA10. Polaron Effect on the Absorption Edge in Silver-Halide Crystals. JOSEPH BROWN AND E. L. OFFENBACHER, *Temple University.*—Utilizing the probability distribution for phonons in the polaron cloud, in the manner of Lee, Low, and Pines[1] for polar crystals, a relationship is derived for the variation of the absorption coefficient with wavelength near the ultraviolet absorption edge. Extending the calculation of Fulton[2] one obtains the effect of the increase in polaron self-energy with temperature on the shift of the absorption edge. This is added to the Radkowsky[3] shift according to the calculation by Callen.[4] The results of the calculation fit fairly well the experimental curves of Gilleo,[5] and Moser and Urbach.[6] The results are valid for absolute zero up to room temperature.

[1] Lee, Low, and Pines, Phys. Rev. **90**, 297 (1953).
[2] T. Fulton, Phys. Rev. **103**, 1712 (1956).
[3] A. Radkowsky, Phys. Rev. **73**, 749 (1948).
[4] H. B. Callen, Phys. Rev. **76**, 1394 (1949).
[5] M. A. Gilleo, Phys. Rev. **91**, 534 (1953).
[6] F. Moser and F. Urbach, Phys. Rev. **102**, 1519 (1956).

FA11. Theory of the Polaron.* E. P. GROSS, *Brandeis University*, AND C. WILLIS, *Syracuse University.*—We study the energy spectrum and eigenfunctions of the polaron Hamiltonian, for which the interaction of electron and lattice vibrations is linear in the creation and annihilation operators a_k^+, a_k of of lattice quanta. The unitary transformation $u = \exp s$, $s = \Sigma_k [a_k \varphi_k^*(q) - a_k^+ \varphi_k(q)]$ is introduced. $\varphi_k(q)$ depends on

the electron coordinate q but also contains parameters representing averages over the electron state. The new lattice coordinates are measured with respect to a weighted function of instantaneous and average electron coordinates which depends on the coupling strength. The transformed Hamiltonian is a quadratic form in a_k, a_k^+. For the lowest state we take trial functions $\psi(q)\cdot\Phi(a_k^+a_k)$. With Φ equal to the vacuum state the choice ψ equal to a plane wave and $\varphi_k(q)$ depending only on the instantaneous electron coordinate leads to intermediate coupling theory. A localized ψ and $\varphi_k(q)$ depending only on average electron state yields the strong limit. With more general φ_k, ψ, Φ we obtain the physical effects of the small oscillation theory and an accurate description of the transition region. The results are readily generalized to the case of many electrons.

* Research supported by the Office of Scientific Research.

FA12. Compression of Solidified Hydrocarbons at 77°K.* JOHN W. STEWART, *University of Virginia.*—Measurements to 20 000 kg/cm² of the compressions of five solidified hydrocarbons, listed below in order of decreasing plasticity at 77°K, have been made using the apparatus and technique previously described.[1,2] All the data can satisfactorily be represented in terms of Murnaghan's theory of finite strain.[3] At 20 000 kg/cm², the over-all compressions $-\Delta V/V_0$ are: methane 0.30, ethane 0.20, ethylene 0.22, propylene 0.21, and propane 0.17. Of the group, only solid methane shows polymorphic behavior. A volume discontinuity occurring at $P=10\,500 \pm 1500$ kg/cm² is of the order of 2% of V_0. Friction in the samples and the overpressure necessary to initiate the transition limit the precision of measurement. It is not known whether this apparent first-order phase change is related to the well-known orientational transition occurring at 20.4°K at atmospheric pressure.[4] Measurements of the compression of methane at 65°K are in progress.

* Supported by the Office of Ordnance Research, U. S. Army.
[1] J. W. Stewart, Bull. Am. Phys. Soc. Ser. II, 1, 218 (1956).
[2] J. W. Stewart, J. Phys. Chem. Solids 1, 146 (1956).
[3] K. Clusius, Z. physik. Chem. **B3**, 63 (1929).

THURSDAY AFTERNOON AT 2:00

Sheraton-Park, Burgundy Room

(M. S. LIVINGSTON presiding)

Accelerators

G1. A-48 High Current Linear Accelerator.* D. H. BIRDSALL, A. F. CLARK, R. C. JOPSON, P. V. LIVDAHL, L. SMITH, AND C. M. VAN ATTA, *University of California, Livermore.*—The A-48 is a 48-Mc linear accelerator of the Alvarez type[1,2] which has so far produced 75 ma of protons, 30 ma of deuterons, and somewhat less than 1 ma of alpha particles with energies of 3.7, 7.5, and 15 Mev, respectively. The beam is mostly less than 2 in. in diameter with an angular divergence of about 1°, and an energy spread of the order of 10%. However, the intensity and angular divergence are peaked at the center. A dc injector operates at voltages up to 135 kv. Next come two drift tubes on quarter-wave stems, resonant at 24 Mc, which increase the proton energies to 500 kev. Two 20-ft-long cylindrical cavities accelerate the protons to 1.8 and 3.7 Mev, respectively. These cavities resonate in the TM_{010} mode at 48 Mc with the drift tubes in position. Radial focusing is provided by solenoids inside each drift tube. Present targets dissipate as much as 15 kev per square inch on a metal sheet with high-speed water cooling on the back face; therefore, large areas are necessary to handle the total beam power. The machine is being improved and used for research.

* Work supported by the U. S. Atomic Energy Commission.
[1] Alvarez *et al.*, Rev. Sci. Instr. **26**, 111 (1955).
[2] E. O. Lawrence, Science **122**, No. 3180, 1127 (1955).

G2. Composite Electrode Positive Ion Acceleration Tube.* C. M. TURNER, *Brookhaven National Laboratory.*—Further evidence has been acquired in support of the hypothesis that ionization loading,[1] or the "ionization chamber effect" is an important consideration in the performance of electrostatic accelerators. The anomaly that aluminum electrodes perform better, in general, in tubes operated at high total voltages than electrically more durable materials, such as stainless steel, appears explanable only on the basis of this effect, with its lower atomic number giving reduced efficiency for bremsstrahlung production under impact of back accelerated electrons. The introduction of supplementary means for bremsstrahlung suppression reduces the "total voltage effect" to the point where the weakness of aluminum as regards interelectrode breakdown becomes apparent. A tube employing composite electrodes—stainless steel to support the high inter-electrode fields and beryllium to define the central aperture—has been in routine operation for the past year. Performance to date has been entirely satisfactory. This tube appears to be electrically stronger than the gradient column in which it is employed. A second model including also periodic absorbers and double re-entrant electrodes is under construction.

* Work performed under the auspices of the U. S. Atomic Energy Commission.
[1] C. M. Turner, Phys. Rev. **95**, 599(A) (1954).

G3. Correction of Remanent Field Effects in an Alternating Gradient Synchrotron Magnet by Demagnetization. JAMES P. PALMER AND ROBERT H. PHILLIPS, *Brookhaven National Laboratory.**—Experiments with strong focusing magnet models show that the field index (defined as the ratio of field gradient to the orbit field) which is supposed to remain constant in both x and t throughout the excitation cycle, is not constant at the injection field of 123 gauss. The remanent magnetic field configuration vitiates the constancy in $n(x,t)$ in several ways which will be explained. A simple method of demagnetization, with a small reverse pulse, is shown to essentially eradicate the remanent history. The field index, which now depends only on the dynamic performance of a magnet, is shown to be maintained closely at the design value for reasonable variations in steel properties.

* Work carried out under contract with U. S. Atomic Energy Commission.

G4. Investigation of the Field Modulation Produced by Flat Spiral Shims in a Cyclotron Magnet.* J. CARROLL, V. BLUEMEL, AND P. STÄHELIN, *University of Illinois.*—Measurements have been made in a 16-in. model magnet of the field modulation (or "flutter") produced by spiral shims. In polar coordinates (R,ϕ), the leading and the trailing edges of the shims are given by $\phi(R)=a(R)+n\pi/N$, where N is the number of shims on each pole face. An analytic approximation which

relates the experimentally determined flutter to the shape of the shim will be given. By maximizing the axial focusing effect of the spiral shims, the equation for the most efficient spiral shape may be obtained. This optimum spiral is approximated by the equation $\alpha(R)=0.48\ (2R/g)$, where g is the average pole gap. Some possible design parameters for cyclotrons of various sizes will be discussed.

* Work supported by Office of Naval Research.

G5. Square-Wave Cyclotron Oscillator. C. D. GOODMAN AND N. F. ZIEGLER, *Oak Ridge National Laboratory.**—To avoid radial spreading of the beam in the proposed Oak Ridge fixed-frequency, high-energy cyclotron, it is necessary either to replace the usual sine-wave accelerating voltage with a square wave or to inject into a very small phase angle of the sine wave. A square wave, however, would ease the accuracy requirements of the machine. Such a wave form would also improve the operating of conventional fixed frequency cyclotrons. Since usual methods of generating square waves are dissipative in principle, they would be too costly in power at cyclotron voltages. For this reason methods which in principle store all the energy must be sought. One feasible solution is to add to the fundamental frequency a third harmonic to produce an approximate square wave. A simple scheme to make a system resonate at two frequencies, one of which is three times the other, has been devised and a model square-wave oscillator utilizing this scheme has been set up.

* Operated for the U. S. Atomic Energy Commission by Union Carbide Nuclear Company.

G6. Microtron (Electron Cyclotron) Yield as Determined by Field Emission Sources Internal and External to the Resonator. H. F. KAISER, *U. S. Naval Research Laboratory.*—The microtron is a microwave electron accelerator differing from a linear microwave electron accelerator mainly in that one resonator is used instead of a plurality of these. The microtron should have a beam in the cavity which is only some multiple of the equivalent "linac" beam of the same final energy. The output beam of a microtron ranges from 1 to 10^{-4}, or lower, microamperes average, while that of existing "linacs" is 0.1 to 300 μa average. The actual cavity beam load of microtron resonators is 0.25–1.50 amp peak or 100–1000 μa average. Electrons are produced by an extended field emission source and the acceptance for injection into acceleration orbits is a few percent at best. It is possible by more efficient field injection technique to increase the microtron yield to a value comparable to that of a "linac," which is very desirable in view of the microtron's compactness. This possibility is being studied: (a) by analysis of the injection trajectories by experimental beam measurement; (b) by theoretical analysis of trajectories from extended and localized field emission sources (including biased and pulsed sources which may operate independently and in arbitrary phase relationship with the microtron resonator); and (c) analysis of electron phase and orbit behavior in transition to outer orbits.

G7. Radial Stability of Orbits in Small Spiral Ridge Cyclotrons.* P. STÄHELIN,† *University of Illinois.*—Even comparatively small cyclotrons ($E_p \lesssim 10$ Mev) may be improved by a spiral modulation of the magnetic field, since this increases the axial stability of the particle orbits.[1] Such a field modulation in an axially symmetric pattern does not affect the radial stability of well centered orbits. However, because of varying initial conditions, most of the actual orbits are not exactly centered. The resulting asymmetry of the magnetic field with respect to these orbits may render them radially unstable. This effect is large for small particle velocities ($v^2 \ll c^2$), because, in this case, the frequency of orbital revolutions and the frequency of radial oscillations are nearly equal, and any perturbation of the orbits is thus enhanced by resonance. An analytical investigation of the stability conditions shows that sufficient stability can be achieved with four or more ridges on each pole face.

* Work supported in part by the Office of Naval Research.
† Assisted by the Swiss Science Foundation.
[1] Symon, Kerst, Jones, Laslett, and Terwilliger, Phys. Rev. 103, 1837 (1956).

G8. Analytical Theory of Radial Sector FFAG Orbits.* F. T. COLE,† *Midwestern Universities Research Association.*—In radial sector FFAG accelerators the variation of the median plane magnetic field in the azimuthal direction (the direction of particle motion) is large compared to its azimuthal average. Because of this large variation, the equilibrium (closed) orbit, which is that orbit with the period of the structure, undergoes large oscillations about a circle. The analytical methods used in the discussion of spiral sector FFAG accelerators[1] do not give accurate expressions for the equilibrium orbit because the variation of the field is so large compared to its average. Approximate analytical expressions have been found for this equilibrium orbit by a variation-iteration technique, which includes "mixing" effects of various Fourier components on each other. The free (betratron) oscillations about this orbit are strongly affected by the oscillations of the equilibrium orbit because of the inherent nonlinearities of FFAG. The equations of motion of these betratron oscillations have been derived. Solutions will be discussed and comparisons with digital computer results given for the nonlinear motion.

* Supported by the U. S. Atomic Energy Commission.
† On leave from the State University of Iowa.
[1] Symon, Kerst, Jones, Laslett, and Terwilliger, Phys. Rev. 103, 1837 (1956).

G9. Radio-Frequency Experiments with a FFAG Accelerator. I. Methods.* KENT M. TERWILLIGER† AND LAWRENCE W. JONES,† *Midwestern Universities Research Association.*—The attainment of very high intensity beams and the practicality of circulating intersecting beams in FFAG accelerators depend heavily on the successful application of the Symon-Sessler[1] radio-frequency acceleration theory. The FFAG electron accelerator described earlier[2] is being used with a combination of betratron and rf acceleration to study various phases of this theory. A betratron pulse accelerates the beam to an intermediate energy, where it is allowed to coast. Then one or a number of identical frequency modulated rf accelerating pulses can be applied to the circulating electrons. The starting frequency of these rf pulses can be adjusted so as to sweep through the coasting beam or to pick it up. A second betratron pulse then accelerates all remaining electrons to the target. The first betratron pulse is used to limit the range of frequency modulation required. Polarization of ferroelectric condensers then produces about a 15% frequency change for the rf acceleration.

* Supported by the U. S. Atomic Energy Commission.
† On leave from the University of Michigan.
[1] K. R. Symon and A. M. Sessler, *Proceedings of the CERN Symposium on High Energy Accelerators and Pion Physics* (Geneva, 1956), Vol. I, p. 44.
[2] See reference 1, p. 359.

G10. Radio-Frequency Experiments with a FFAG Accelerator. II. Results.* LAWRENCE W. JONES,† AND KENT M. TERWILLIGER,† *Midwestern Universities Research Association.*—A particular prediction of the Symon-Sessler general rf theory for FFAG accelerators states that an rf pulse, starting at a frequency corresponding to an energy below that of a coasting beam of particles and frequency modulating through it does not capture, but lowers the energy of the coasting beam by a predictable amount. This phase displacement has been tested experimentally with the radial sector FFAG electron accelerator. Measurements of the average energy displacement of the circulating beam by an rf pass through it have been made by two different methods which agree with each other and with the theoretically predicted values to within experi-

mental error. In a second experiment beam of particles coasting at one energy has been transferred (accelerated) to a higher energy by a sequence of identical rf pulses. The resulting energy distribution of the electrons in the vacuum chamber as inferred from the time distribution of beam output from the second betratron pulse indicates a good transfer efficiency. Details of these experiments and numerical results will be presented.

* Supported by the U. S. Atomic Energy Commission.
† On leave from the University of Michigan.

G11. Suppression of Radio-Frequency Knock-Out of Stacked Beams in Fixed Field Accelerators.* D. W. KERST,† *Midwestern Universities Research Association.*—When a large circulating beam is to be stored at high energy in an accelerator while additional particles are being accelerated up to the stacking energy, the frequency modulated accelerating voltage can excite resonant betratron oscillations in the stack at certain frequencies. Methods of suppressing this knock-out have been considered by members of the MURA staff. Some of the methods are: (1) Separate cavities at different orbit radii. (2) Fast passage through knock-out resonance. (3) Multiple-phased cavities to eliminate certain knock-outs and to simulate traveling accelerating waves. (4) Controlled angle of the electric field of a phased pair of cavities spaced a half of a betatron wavelength or less along the orbit at the stacking radius. (5) Jumping over the narrow knock-out frequency with a cavity holding a wide bucket. (6) Programed operations to cancel the excited oscillations. Knock-out resulting from both nontangential electric fields and from discrete energy jumps is important.

* Supported by the U. S. Atomic Energy Commission.
† On leave from the University of Illinois.

G12. Theoretical Analysis of Beam Stacking in Fixed Field Accelerators.* KEITH R. SYMON,† *Midwestern Universities Research Association.*—An important advantage of fixed field accelerators is the possibility of stacking intense beams of circulating particles by acceleration to the stacking energy of successive groups of injected particles.[1] Theoretical analyses and computational results will be presented which permit the calculation of the magnitude and energy distribution of stacked currents which result from any given injection and radio-frequency acceleration process. Stacking processes which make use of betatron accelerations have also been studied.

* Supported by the U. S. Atomic Energy Commission.
† On leave from the University of Wisconsin.
[1] K. R. Symon and A. M. Sessler, *Proceedings of the CERN Symposium on High Energy Accelerators and Pion Physics* (Geneva, 1956), Vol. 1, p. 44.

G13. Preliminary Considerations on the Acceleration of Particles by Reflection of Electromagnetic Waves.* TIHIRO OHKAWA, *Midwestern Universities Research Association.*—It has been proposed by Veksler[1] that there is a possibility of accelerating particles by transferring momenta from photons to particles in "coherent Thomson scattering." When the density of particles is sufficiently high, the scattered wave will interfere with the incident wave and finally a complete reflection occurs. It has been observed that a plasma in a microwave system reflects or attenuates the wave strongly. With a cloud of charged particles inside the guide, the cut-off frequency of the guide is higher than that of the guide alone. When a wave having frequency between the two cut-off frequencies encounters the cloud in the guide, it will be reflected completely. Therefore the momentum carried by the wave must be transferred to the particles provided that the phase and group velocities are higher than the velocity of the particles. This method of acceleration appears feasible with the realistic densities of particles and microwave frequency and power. Since the necessary density of particles is considerably lowered by using a frequency near cutoff for the wave, the acceleration per particle is large compared to Veksler's original scheme.

* Supported by the U. S. Atomic Energy Commission.
[1] V. I. Veksler, *Proceedings of the CERN Symposium on High Accelerators and Pion Physics* (Geneva, 1956), Vol. 1.

THURSDAY AFTERNOON AT 2:00

Shoreham, West Ballroom

(A. PAIS presiding)

Theoretical Physics II: Field-Theory and Symmetry Properties

GA1. Extended Source Theories and Gauge Invariance. CHARLES ZEMACH, *University of Pennsylvania.*—The nucleon, in interaction with mesons and photons of low energies, is often regarded as a static extended source. The Hamiltonian for the system then includes an electromagnetic "interaction current" which is required, but only partially specified, by the principle of gauge invariance. The validity of the extended source model may be confirmed and the ambiguity in the form of the interaction current may be removed by a suitable derivation of the static limit from the relativistic theory. The renormalization procedure is modified to permit the replacement of the unrenormalized meson coupling constant, not by its renormalized counterpart, but by a form factor which describes the complete interaction of a meson with a free nucleon. Alternative renormalizations provide a freedom of choice in the extent to which phenomenological information may be implanted into the theory. Computed corrections to quantities already in phenomenological form must then be disregarded. In this formulation one may show that the prescription $p \rightarrow p - eA$ accounts completely for electromagnetic interactions. This rule is mathematically equivalent to the customary procedure in which the nucleon source function is multiplied by the exponential of a certain path integral provided that the path of integration is a straight line.

GA2. Theory of Fields of Integral Spin Greater than One.* PETER HAVAS, *Lehigh University.*—Equations describing wave fields for any integral spin have been established by Fierz.[1] Although the general form of the equation of motion of singularities of such fields was deduced by Harish-Chandra,[2] this does not assure the existence of a self-consistent theory of arbitrary point singularities. A general theory of multipole singularities of spin zero fields was given recently,[3] and the equations of motion of poles and dipoles of spin one fields are well known. For spins greater than one it has been found, however, that it is not possible to have simple poles whose fields satisfy all of Fierz' conditions. It appears that while higher poles are compatible with the field equations, no consistent equations of motion are possible for them. Due to this absence of interaction such fields are unobservable. Thus, at least

within the framework of classical linear field theories, interaction of particles appears to be possible only through (neutral or charged) fields of spin zero or one.

* Research supported in part by the Air Force Office of Scientific Research.
[1] M. Fierz, Helv. Phys. Acta **12**, 3 (1939).
[2] Harish-Chandra, Proc. Roy. Soc. (London) **A185**, 269 (1946).
[3] P. Havas, Phys. Rev. **93**, 1400 (1954).

GA3. Test for Tomonaga's Method of Intermediate Coupling.* CHARLES ROBERTS† AND JAMES L. ANDERSON‡, *University of Maryland*.—In his original presentation[1] Tomonaga applied his intermediate coupling scheme to this case of charged scalar meson theory interacting with fixed source nucleons. A calculation of the nucleon self-energy was shown to agree with both the weak and strong coupling approximations. Since the Tomonaga method essentially neglects effects of meson correlation it is not too surprising that it gives reasonable results for this theory. A more stringent test of the approximation would be to apply it to a theory in which meson-meson interactions play a role. At the same time the theory should possess an exact solution so that a measure of the goodness of the approximation can be made. Such a theory is the Wentzel pair theory. The ground state self-energy of the nucleon is calculated both directly and by means of the Tomonaga approximation for various values of the coupling constant. There is a maximum error of 20% in the intermediate coupling range.

* Work supported by National Science Foundation.
† Now at Long Beach College.
‡ Now at Stevens Institute of Technology.
[1] S. Tomonaga, Progr. Theoret. Phys. (Japan) **II**, 6 (1946–1947).

GA4. Scattering and Polarization of Spin-3/2 Particles.* SAUL BARSHAY, *University of California, Berkeley*.—General expressions describing the single and double scattering of a spin $\frac{3}{2}$ particle by spin-zero targets have been derived. The set of mutually orthogonal operators that span the spin space is comprised of the unit matrix, and first-, second-, and third-rank tensors with three, five, and seven components respectively. The amplitude describing the initial scattering is written as a matrix in the spin-orbital angular momentum space operating on the incident wave function. This matrix is constructed from a complete set of projection operators in the spin-orbit space. The coefficients of the projection operators are functions of the phase shifts for the scattering in the various states of given orbital and total angular momentum. For simplicity we limit the discussion to S and P waves. Expressions in terms of the phase shifts and scattering angle are obtained for the differential cross section for an initially unpolarized beam and for the expectation values of the sixteen spin operators in the scattered beam. A second scattering may be used to analyze the components of polarization, and the differential cross section may be written in the form $a+b\cos\phi+c\cos2\phi$, where ϕ is the angle between the normals to the planes of the two scatterings.

* This work was performed under the auspices of the U. S. Atomic Energy Commission.

GA5. Asymptotic Condition in Quantum Field Theory. O. W. GREENBERG, *Brandeis University*.—The asymptotic condition is the requirement that a field theory have an interpretation in terms of asymptotic particle observables, that is, in terms of observables for stationary incoming and outgoing beams of particles which have the same transformation, statistical and orthogonality properties as free particles of a given mass. These asymptotic observables are the operators used in defining the S matrix. The asymptotic observables are constructed using the in and out operators, which are defined in terms of the Heisenberg field operator by means of the asymptotic limit. For a large class of nonrelativistic field theories it is shown that the in and out operators are the strong limit of the Heisenberg operator in a precisely defined sense. For local relativistic theories it is shown that, even for theories with infinite wave-function renormalization, the in and out operators exist as a weak limit of the Heisenberg operator and have the transformation properties of free fields of a given mass. It is shown that the in and out fields obey the free field commutation rules, although the argument is not rigorous for theories with infinite wave-function renormalization. The Yang-Feldman equations for both relativistic and nonrelativistic theories are derived from the definition of the in and out operators.

GA6. Two-Body Amplitudes for Boson Fields.* F. L. SCARF AND H. UMEZAWA†, *University of Washington*.—In an attempt to determine the number of acceptable solutions of the two-body equation for bosons, scalar fields are quantized using two-component field operators which satisfy linear Sakata-Taketani (S.T.) equations instead of the usual Klein-Gordon (K.G.) equations. The corresponding Bethe-Salpeter equation for the four-component function $\chi(a,b)$ (S.T.) is linear in the two energies in contrast to the second-order Wick equation for the function $\Phi(a,b)$ (K.G.). A conservation equation for $\bar{\chi}\chi$ is obtained and in the limit $m_b\to\infty$ it reduces to the correct single particle form. Also, when retardation is neglected, the S.T. formalism leads to a Breit equation. A transformation $\chi_{a\beta}=S_{a\beta}\Phi$ is found and $\bar{\chi}\chi$ is examined (using Wick's results for Φ) as the interaction is adiabatically switched off. Only the states with $\kappa=0$ (all n,l,m) have bounded $\bar{\chi}\chi$ for all finite values of the interaction constant and this suggests that the spurious ($\kappa>0$) solutions arise when the inhomogeneous term is eliminated. Similar results are found for the two-fermion problem with vertex operators of the form $(1+\gamma_5)$.

* Supported in part by the U. S. Atomic Energy Commission.
† Permanent Address: University of Tokyo.

GA7. Some Consequences of TCP Invariance. G. LÜDERS,* *MIT*, AND B. ZUMINO, *Stevens Institute of Technology*.—In the light of recent experiments on the violation of parity and charge conjugation we have investigated which connections between the properties of particles and antiparticles follow from the general invariance[1] with respect to the product of time reversal (T), charge conjugation (C), and parity (P) and which can only be deduced from more severe invariance requirements. It is shown that masses and lifetimes of particles and antiparticles are strictly equal as a consequence of TCP alone. The same holds for branching ratios into corresponding decay channels, calculated to first order in the weak interaction, if the strong interaction does not induce scattering between different channels. Consequences of these considerations for for the decay of K^+ and K^- will be discussed.

* Smith Mundt Grantee, on leave of absence from Max-Planck-Institut fur Physik, Göttingen.
[1] J. Schwinger, Phys. Rev. **82**, 914 (1951); G. Lüders, Dan. Mat. Fys. Medd. **28**, No. 5 (1954); W. Pauli in *Niels Bohr and the Development of Physics* (New York, McGraw-Hill Book Company, Inc., 1955).

GA8. Polarization of β Rays and Parity Nonconservation. L. WOLFENSTEIN, *Carnegie Insittute of Technology*, AND L. PAGE, *University of Pittsburgh*.—Yang and Lee have suggested that parity may not be conserved in β decay and this has been confirmed by recent experiments.[1] One consequence of parity nonconservation is that β rays may be polarized parallel to their direction of motion. For allowed transitions the maximum of this polarization is calculated to be (V/c), where V is the electron velocity. If the Yang-Lee neutrino theory is used, this maximum value is achieved. This result is true for either a pure Fermi or a pure Gamow-Teller transition (and also for any combination of scalar and tensor interactions), in contrast to experiments on polarized nuclei[2] which can yield no evidence on the Fermi interaction. To measure the polarization the β^- rays are passed through crossed electric and magnetic fields so as to turn the spin to a direction per-

pendicular to the electron momentum and are then scattered from gold. The resulting left-right asymmetry measures the polarization. Such an experiment is now in progress.

[1] T. D. Lee and C. N. Yang, Phys. Rev. **104**, 254 (1956).
[2] T. D. Lee *et al.*, New York Times **106**, No. 36152, 24 (1957).

GA9. Radiative Corrections to the Decay of Polarized μ Mesons and the Two Component Theory of Neutrinos.* T. Kinoshita and A. Sirlin, *Cornell University.*—Recent experiments[1] on the $\pi-\mu-e$ decay have proved that the parity is not conserved in these decay processes.[2] The two component theory of neutrinos proposed by Lee and Yang[3] seems to explain the spectrum of the electron from μ-meson decay reasonably well. To determine whether this particular theory is correct, the radiative corrections to the energy angle distribution of the decay electron have been calculated. Both the contributions of the virtual photons and the inner bremsstrahlung are calculated using a technique developed before.[4] Since the two component theory of neutrinos admits only the vector and axial vector interactions in the change retention order, the final result is free from the ultraviolet divergences. The magnitude of the radiative correction amounts to about 5% and thus it would be necessary to include this effect to have an accurate determination of the asymmetry parameter and to establish the validity of the two component theory of neutrinos.

* Assisted by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.
[1] Lederman, Garwin, and Weinrich, Phys. Rev. (to be published).
[2] T. D. Lee and C. N. Yang, Phys. Rev. **104**, 254 (1956).
[3] T. D. Lee and C. N. Yang, Phys. Rev. (to be published).
[4] Behrends, Finkelstein, and Sirlin, Phys. Rev. **101**, 866 (1956).

GA10. Nonconservation of Parity and τ-Meson Decay.* E. Lomon, *Cornell University.*—The neglect of the assumption of parity conservation with regard to weak interactions has an important consequence for the phenomenological analysis of the τ-meson decay. The final state may be assumed to be a mixture of even and odd states of the 3-pion system for any given total spin. This removes the major difficulty in conceiving the θ and τ mesons to be two decay modes of the same particle. We have examined the energy and angular distributions of the odd pion in the τ-meson decay when both parity modes are allowed in the final state. Recent work[1] has indicated that the fit is poor for all spins, when parity is conserved. The combination of states of both parities substantially improves only the spin 2 case. Using only the lowest order terms of the Fabri expansion, and a real ratio of the coefficients for the degenerate $[2-]$ case, it is possible to obtain an excellent fit. No inteference is required between the states of opposite parity. This is consistent with invariance to charge conjugation.[2]

* Supported in part by joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.
[1] Eisenberg, Lomon, and Rosendorff, Nuovo cimento **4**, 610 (1956). The addition of the Coulomb effect makes the $[0-]$ fit worse.
[2] Lee, Oehme, and Yang, Phys. Rev. (to be published).

GA11. Isotopic Spin Selection Rule $\Delta I=\frac{1}{2}$ for the Decays of Heavy Unstable Particles.* Masaaki Kawaguchi, *Purdue University.*—Decay processes of heavy unstable particles are re-examined under the assumption of the selection rule $|\Delta I|=\frac{1}{2}$, when all particles concerned have isotopic spins, but parity is not necessarily conserved. Some of the results obtained before[1] still hold as they are, even if parity nonconservation is taken into consideration. However, the relation between the branching ratio $(\Sigma^+\to n+\pi^+)/(\Sigma^+\to p+\pi^0)$ and the ratio of lifetimes $\tau(\Sigma^+)/\tau(\Sigma^-)$ is changed by parity nonconservation. The experimental results on Σ_1 particles may be interpreted as indicating comparable magnitudes for parity conserving and nonconserving terms. Some results based on $|\Delta I|=\frac{1}{2}$ and $\frac{3}{2}$ are also discussed for K particles.

* Assisted by Air Force Office of Scientific Research.
[1] For example, M. Kawaguchi and K. Nishijima, Progr. Theoret. Phys. (Japan) **15**, 180 (1956).

GA12. Parity Nonconservation and the Group-Space of the Proper Lorentz Group. E. J. Schremp, *Naval Research Laboratory.*—As a means of incorporating isotopic spin into the foundations of the theory of spin $\frac{1}{2}$ particles, a slight modification of the free-particle Dirac equations has previously been proposed which follows from a consideration of the group-space of the proper Lorentz group. Further considerations of the group-space suggest two additional modifications, which have been used to define a 3-dimensional manifold of generalized plane-wave representations of a free spin $\frac{1}{2}$ particle. Through this extended manifold, a free spin $\frac{1}{2}$ particle is invariantively characterized, in its own preferred frame of reference, by constant 4 vectors of momentum P and spin density σ, and by a rest mass M which may equal or exceed the rest mass m of the corresponding free Dirac particle. In the exceptional case $M=m=0$, there are here admitted not one but two discrete positive energy plane wave representations of the neutrino, with their spins completely polarized (in 3-space) parallel and antiparallel to their respective momenta. The corresponding generalization of the Dirac theory for $m\neq 0$, which may be regarded as reducing to the latter when P and σ become mutually orthogonal, attributes to the general spin $\frac{1}{2}$ particle (e.g., the μ meson) a similar bifurcation into pairs of relativistically invariant states of opposite (4-dimensional) spin polarization, which coalesce for a Dirac particle.

Thursday Afternoon at 2:00

Shoreham, Main Ballroom

(M. M. Shapiro presiding)

Cosmic Rays; Antiprotons, Antineutrons

H1. Primary Alpha-Particle Spectrum and Geomagnetic Cut-Off Energies. P. Freier, P. F. Fowler, and E. P. Ney, *University of Minnesota.*—The differential energy spectra of cosmic-ray alpha particles have been measured at the top of the atmosphere at the following locations. The latitudes and longitudes are geographic and correspond to the mean location of the balloon at altitude (see Table I).

The differential spectra in Canada and northern Iowa are alike and show a maximum as previously reported. Primary alpha particles are present down to energies of 150 Mev/nucleon at these latitudes. It is believed that this spectrum represents the energies of cosmic rays before entering the earth's magnetic field. The spectra in Missouri and Texas do not contain low-energy particles. The Missouri data allow

TABLE I.

Launching Site	Latitude	Longitude
Saskatoon, Canada	52°10′N	107° W
Waukon, Iowa	43°50′N	91.5°W
Kirksville, Missouri	40°40′N	90° W
San Angelo, Texas	31° N	101° W

the determination of the cosmic-ray latitude of Missouri and indicate that the cosmic-ray geomagnetic latitudes at geographic longitude 90°E are higher than the latitude derived from conventional geomagnetic coordinates. Our measurements together with the English measurements and the assumption of dipole deflection of cosmic rays would fix the location of the North magnetic pole at latitude 75.5° and longitude 90°W.

H2. Proton and Alpha Intensity of Primary Cosmic Radiation near the Geomagnetic Equator.* FRANK B. MCDONALD, *State University of Iowa.*—A combination Scintillation counter-Čerenkov counter detector, similar to those previously described,[1] has been flown from Guam. The apparatus was carried to a residual pressure of 6 g/cm² for a period of 5½ hours. This flight was part of the Office of Naval Research 1957 Equatorial Balloon Expedition. An absolute value for the vertical primary alpha-particle intensity will be presented. In addition, an accurate upper limit on the primary proton flux can be made and values for the flux of fast upward moving, or albedo particles, will be given.

* Assisted by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.
[1] F. B. McDonald, Phys. Rev. **104**, 1723 (1956).

H3. Heavy Nuclei in the Primary Cosmic Radiation at 41°N and Their Interactions.* MASATOSHI KOSHIBA AND MARCEL SCHEIN, *University of Chicago.*—A stack of 100 G-5 emulsions of 6×12 in.×600 μ was flown at Texas, 41°N, to an altitude of 100 000 ft for 10 hr. The stack was used for the study of the heavy nuclei component in the primary cosmic radiation. So far, about 500 heavy nuclei, including the Li–Be–B group, which have zenith angles smaller than 30° and length per plate greater than 2 mm, have been located and traced through the stack. Because of the greater observational length of these heavy nuclei tracks, minimum of 5 cm and maximum of 30 cm, most of them interacted before leaving the stack. The results on the charge spectrum, energy spectrum, and the fragmentation probabilities of these heavy components will be presented.

* Supported in part by a joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.

H4. On the Flux of Cosmic-Ray Particles with $Z \geq 2$ at $\lambda = 41°$N.* A. ENGLER, M. F. KAPLON, AND J. KLARMANN, *University of Rochester.*—A stack of nuclear emulsions has been exposed to the cosmic radiation under ~8 g/cm² of matter at $\lambda = 41°$N. Since at this latitude all incoming particles are nearly relativistic, ionization measurements are sufficient to determine their charge. Blob-and-gap measurements were made on the tracks of α particles, and δ-ray counts on those of particles with $Z \geq 3$. The obtained fluxes will be presented and compared with those of other authors.

* This research was supported in part by the Office of Scientific Research, Air Research and Development Command, U. S. Air Force.

H5. Changes in the Low-Energy Particle Cutoff and Spectrum of the Primary Cosmic Radiation.* PETER MEYER AND J. A. SIMPSON, *University of Chicago.*—It has been reported earlier that the primary cosmic-ray spectrum observed at the earth had changed between 1948 and 1951. These changes included a decrease in the energy for the low-energy cutoff, an increase in total particle intensity and a change in the power law spectrum. The effects appeared to be related to the general level of solar activity. New measurements carried out in August, 1956 when the level of solar activity had greatly increased, show that the shift of the low-energy cutoff to a very small value is restricted in time to an interval in which the solar activity reached a minimum in the 11-year solar cycle. Further changes in the power law spectrum and total cosmic-ray intensity were found. The new results further support the view that these changes in the primary spectrum have their origin in a mechanism controlled by solar activity.

* Assisted in part by the Office of Scientific Research and the Geophysics Research Directorate, AF Cambridge Research Center, Air Research and Development Command, U. S. Air Force.

H6. Decrease of the Earth's Shadow Effect on Cosmic Rays with Increase in Observation Altitude.* MELVIN SCHWARTZ,† *State University of Iowa.*—The fact that an earth satellite will make cosmic-ray measurements at altitudes of several hundred miles and up raises the problem of extending the Lemaitre-Vallarta theory of the allowed cone[1] to take account of the decrease of the earth's shadow effect with increasing observation altitude, and resulting observation from below the horizon. The complete solution of this problem for the equatorial plane will be outlined and used as a basis for indicating the solution to the problem at higher latitudes. Work on the nonequatorial part of the problem is now in progress both at Iowa and at Rutgers. The author would like to thank Professor J. A. Van Allen for suggesting the problem and Mr. R. Lynch for numerical work and discussions.

* Assisted by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.
† Now at Rutgers University.
[1] G. Lemaître and M. S. Vallarta, Phys. Rev. **50**, 493 (1936).

H7. Cosmic-Ray Decreases During Magnetic Storms.* S. F. SINGER, *University of Maryland.*—Worldwide decreases of cosmic-ray intensity often occur during the main phase of magnetic storms. These Forbush-type events have been ascribed to the Störmer ring current (Chapman), or to a solar corpuscular beam (Alfvén). Morrison, and more recently Parker, have postulated a highly turbulent magnetic field structure which partially screens the earth from cosmic rays by reflecting many particles without, however, changing their energy. In contradistinction, we consider here that the Forbush events result from a *deceleration* of cosmic rays; the energy decrease is produced in an inverse Fermi process which is set up as turbulent centers caused by a solar eruption expand outward and decay. Numerical estimates support this view. Crucial experimental tests will be discussed: (i) a possible shift in the position of the knee of the energy spectrum; (ii) the spectrum of heavies compared to protons; and (iii) the cosmic-ray intensity at extremely large distances from the earth.

* Supported in part by Air Force Office of Scientific Research.

H8. Mu Mesons in Extensive Air Showers.* J. A. EARL, *MIT.*—The MIT air shower experiment gives the size, core location, and arrival direction of each shower triggering the apparatus. The penetrating component of these showers has been observed with the aid of a large hodoscope shielded by 900 g/cm² of lead. Two 48 in. by 48 in. hodoscoped trays of Geiger tubes are placed one above the other so that the projected zenith angle of mesons traversing the trays can be measured. Mu mesons associated with the shower are identified by requiring this projected zenith angle to agree with the known arrival direction of the shower. Results obtained to date on the lateral distribution of mu mesons for showers of three size ranges—3×10^5 to 10^6, 10^6 to 3×10^6, and 3×10^6 to

10^7 electrons—are consistent with a r^{-4} density distribution for r between 30 and 150 m.

* Supported in part by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission and in part by a grant from the National Science Foundation.

H9. Cosmic-Ray Jet in the 10^{14} Electron Volt Energy Range. P. F. Fowler, C. G. M. Lattes, P. Freier, and E. P. Ney, *University of Minnesota.*—A 20-liter stack of emulsions was exposed in Minnesota in September, 1956 in a cooperative experiment with the University of Bristol. The pellicle stack weighed 200 pounds and had dimensions of 16 by 12 by 7 in. The largest jet so far found by naked eye scanning traversed the entire Minnesota half of the stack with a total length of 29 cm. In these 10 radiation lengths the jet multiplied from 9 particles, mainly in 2 cores to approximately 10 000 particles. The electromagnetic cascade appeared to be initiated by several γ rays, perhaps from the decay of two neutral mesons. As in the case of the only other very large jet of this kind which has been observed at Bristol, there is a low multiplicity of mesons in the initial event.

H10. Interactions of Antiprotons in Nuclear Emulsion.* J. Sandweiss, W. Chupp, and G. Goldhaber, *University of California, Berkeley.*—In continuing the study of antiprotons, we have exposed several additional nuclear emulsion stacks[1] under conditions similar to those reported previously.[2] In these stacks 58 antiprotons have been found. The mean free path for nonelastic $\bar{p}$ interactions in the energy interval 50 to 200 Mev, as computed from 93 antiprotons (including 35 antiprotons from reference 2) is 15.1 ± 2.7 cm. This corresponds to $\sigma_{\bar{p}}/\sigma_0 = 2.4 \pm 0.4$, where $\sigma_0 = \pi(1.2A^{\frac{1}{3}})^2$. To date a total of 4 m of $\bar{p}$ track has been examined for scatterings with a projected angle $\geq 2°$. For each of these the space angle of scattering has been measured, and the results are shown in Table I. For

Table I.

Scattering angle	Observed	Number of events Rutherford	Diffraction
2°–4°	6	15.1	3.6
4°–6°	6	4.7	5.4
6°–20°	14	3.0	9.9

comparison we give the number of events expected from point-nucleus Rutherford scattering and from black-sphere diffraction scattering with $\sigma_{\bar{p}}/\sigma_0$ as given in the foregoing.

* This work was done under the auspices of the U. S. Atomic Energy Commission.
† The authors are grateful to the members of the Barkas Group for permission to use their data prior to publication.
[1] Barkas, Birge, Chupp, Ekspong, Goldhaber, Goldhaber, Heckman, Perkins, Sandweiss, Segrè, Smith, Stork, van Rossum, Amaldi, Baroni, Castagnoli, Franzinetti, and Manfredini, Phys. Rev. **105**, 1037 (1957).

H11. Antiproton Absorption Cross Sections in Complex Nuclei.* T. Ypsilantis, D. Keller, R. Mermod, E. Segrè, H. Steiner, C. Wiegand, and O. Chamberlain, *University of California, Berkeley.*—The total absorption cross sections for 450-Mev antiprotons in oxygen, copper, silver, and lead have been measured with laboratory cut-off angles of 14° and 20°. In addition, the total annihilation cross sections for these

Table I.

Element	$\sigma_{abs}(\theta = 14°)$	$\sigma_{abs}(\theta = 20°)$	σ_{annih}
Oxygen	558 ± 10	526 ± 10	388 ± 8
Copper	1156 ± 70	1100 ± 68	912 ± 58
Silver	1600 ± 171	1590 ± 163	1153 ± 132
Lead	2573 ± 282	2535 ± 274	2097 ± 227

elements were obtained by detecting charged mesons from the annihilation process with a Čerenkov counter which subtended almost the entire solid angle. The cross sections (in millibarns) are summarized in Table I.
These results may be compared with our earlier measurements[1] and with the measurements by Cork *et al.*[2]

* This work was performed under the auspices of the U. S. Atomic Energy Commission.
[1] Chamberlain, Keller, Segrè, Steiner, Wiegand, and Ypsilantis, Phys. Rev. **102**, 1637 (1956).
[2] Cork, Lambertson, Piccioni, and Wenzel, Phys. Rev. (to be published).

H12. Antiproton-Proton and Antiproton-Neutron Cross Sections at 450 Mev.* H. Steiner, O. Chamberlain, D. Keller, E. Rogers, E. Segrè, L. Agnew, C. Wiegand, and T. Ypsilantis, *University of California, Berkeley.*—Cross sections for $\bar{p}p$ and $\bar{p}n$ interaction at 450 Mev have been measured using $D_2O - H_2O - O_2$ subtraction at cut-off angles of 14° and 21°. The incident antiprotons were identified by a system of counters and magnets similar to that used in earlier experiments.[1,2] By observing the Čerenkov light produced in the target by fast charged secondaries resulting from antiproton-nucleon annihilations, we were also able to calculate the total $\bar{p}p$ and $\bar{p}n$ annihilation cross sections. The results are compared to pp and pn cross sections obtained with the same geometry. Preliminary results are shown in the following.

	$\sigma(14°)$ (10^{-27} cm²)	$\sigma(20°)$ (10^{-27} cm²)	σ(annih) (10^{-27} cm²)
$\bar{p}p$	141 ± 10	130 ± 9	123 ± 8
$\bar{p}n$	100 ± 15	84 ± 14	67 ± 12
pp	24.6 ± 1.2	23.9 ± 1.3	...
pn	28.4 ± 1.3	21.1 ± 1.1	...

These results will be compared with others obtained in this laboratory.[3]

* This work was performed under the auspices of the U. S. Atomic Energy Commission.
[1] Chamberlain, Segrè, Wiegand, and Ypsilantis, Phys. Rev. **100**, 947 (1955).
[2] Chamberlain, Keller, Segrè, Steiner, Wiegand, and Ypsilantis, Phys. Rev. **102**, 1637 (1956).
[3] Lambertson, Cork, Piccioni, and Wenzel, Bull. Am. Phys. Soc., Ser. II, **1**, 376 (1956).

H13. Antineutron Production by Charge Exchange.* O. Chamberlain, T. Elioff, E. Segrè, H. Steiner, R. Weingart, C. Wiegand, and T. Ypsilantis, *University of California, Berkeley.*—The prediction that antineutrons would be formed by antiprotons by charge exchange[1] has recently been verified.[2] We have utilized this method of production and observed antineutrons produced by 1080-Mev/c antiprotons incident upon CH_2, C, and Pb targets. The antineutrons were detected by their energy release upon annihilation. For this purpose a counter was constructed which consisted of alternate layers of Pb and plastic scintillator such that the thickness along the beam direction was 156 g/cm² Pb and 45.7 g/cm² scintillator. The sensitive volume formed a cube 2 by 2 by 2 in. whose average density was 3.84 g/cc. The counter was viewed by 48 RCA 6810 photomultiplier tubes. Resultant pulse-height spectra for antineutrons and antiprotons were found to be in agreement. Preliminary results indicate that for about 4000 incident antiprotons on each of the substances CH_2, C, and Pb, the numbers of antineutrons produced into a solid angle of 0.7 steradian in the forward direction were 30, 17, and 1, respectively. These results show that $\sigma(p+p \rightarrow n+\bar{n})$ decreases with increasing Z.

* This work was done under the auspices of the U. S. Atomic Energy Commission.
[1] Chamberlain, Segrè, Wiegand, and Ypsilantis, Nature **177**, 11 (1956).
[2] Cork, Lambertson, Piccioni, and Wenzel, Phys. Rev. **104**, 1193 (1956).

THURSDAY AFTERNOON AT 1:45

Sheraton Hall

(W. W. HAVENS presiding)

Invited Papers

HA1. Delayed Neutrons from the Fission of Uranium 235, Uranium 233, and Plutonium 239. G. R. KEEPIN, *Los Alamos Scientific Laboratory.* (30 min.)

HA2. Polarization and Asymmetry of High-Energy Scattered Protons. PETER HILLMAN, *University of Upsala, Sweden.* (30 min.)

HA3. The Many-Body Problem with Strong Forces. R. JASTROW, *U. S. Naval Research Laboratory.* (30 min.)

HA4. The "Twin Paradox" of Relativity. H. W. LEWIS, *University of Wisconsin.* (30 min.)

FRIDAY MORNING AT 9:30

Sheraton-Park, Burgundy Room

(G. BERNARDINI presiding)

Muons and Pions

J1. Nuclear Excitation from μ^- Capture.* SELIG N. KAPLAN, BURTON J. MOYER, AND ROBERT V. PYLE, *University of California, Berkeley.*—Neutron multiplicities from μ^- capture in Pb and Ag have been observed with a cadmium-loaded liquid scintillator tank. The observed distributions previously reported have been compared with the distributions predicted by a Fermi gas model (with both the effective nucleon mass, $M_{neff}=M_n$ and $M_{neff}=M_n/2$), and an α-particle model. Assuming a "boil-off" neutron spectrum, the observed distributions for Pb compare with the predicted distributions as shown in Table I. In the lower multiplicities, where the statistics are better, the Fermi model with $M_{eff}=M/2$ seems to give the best fit. The distribution from Ag will also be discussed.

TABLE I.

	Observed	α-particle model	Predicted Fermi gas model $M_{eff}=M$	Predicted Fermi gas model $M_{eff}=M/2$
$f(0)$	0.315 ± 0.098	0.319	0.515	0.318
$f(1)$	0.506 ± 0.064	0.362	0.474	0.487
$f(2)$	0.146 ± 0.027	0.184	0.010	0.190
$f(3)$	0.019 ± 0.015	0.080	0	0.003
$f(4)$	0.009 ± 0.006	0.034	0	0
$f(5)$	0.002 ± 0.002	0.014	0	0
$f(6)$	0.002 ± 0.002	0.005	0	0

* This work was performed under the auspices of the U. S. Atomic Energy Commission.

J2. Median Angle of Neutral Pion Emission.* D. T. KING, *University of Tennessee.*—A search for electron pairs has been made in nuclear emulsions which had been exposed to the internal 6.2 Bev p^+ beam of the Bevatron. Only those pairs with mean dip angle within $\pm5°$ of the emulsion plane were included; otherwise, the scan was based on a random selection of tracks. From 117 such pairs, the polar angle distribution of the γ rays was derived. The corresponding distribution for the neutral pions may be assumed to be closely similar. The median angle is found to be 30.0°, i.e., about 4.7° larger than that derived assuming simple nucleon-nucleon collision, ignoring internal motions and secondary effects. Thus, a median angle measurement based on neutral pions leads to a low determination of primary energy, in contrast to the result of Haber-Schaim,[1] who used the charged shower particles. The π^0-angular distribution is compared to that expected under simplifying assumptions.

* Supported by the National Science Foundation.
[1] U. Haber-Schaim, Nuovo cimento 4, 669 (1956).

J3. Small-Angle Photomeson Production from Hydrogen.* V. PEREZ-MENDEZ, W. IMHOF, R. W. KENNEY, AND E. A. KNAPP, *University of California, Berkeley.*—The relative differential cross section for photoproduction of positive pions in the angular region from 0° to 53° c.m. has been obtained at a photon energy of 260 Mev, utilizing the 340-Mev bremsstrahlung beam of the Berkeley synchrotron. The mesons were detected by their characteristic $\pi-\mu$ decay. The large background at the forward angles was decreased considerably by magnetically analyzing the pions, requiring them to pass through 2.9 radiation lengths of lead placed halfway down the magnetic channel, and employing a Čerenkov counter in anticoincidence. The mesons were produced in a 0.35-g/cm² liquid hydrogen target, with thin Mylar walls to reduce background. The measured differential cross section has a constant value within statistics from 30° to 0°. Using the CalTech magnet data[1] to normalize our relative cross section, we obtain a value of $(d\sigma/d\Omega)(0)=0.620\pm0.068\times10^{-29}$ cm²/sterad. The observed distribution will be compared with the theory of Chew and Low and the generalized dispersion-relations results, as evaluated by Moravcsik.[2]

* This work was performed under the auspices of the U. S. Atomic Energy Commission.
[1] Walker, Teasdale, Peterson, and Vette, Phys. Rev. 99, 210 (1955).
[2] M. J. Moravcsik, Phys. Rev. 104, 1451 (1956).

J4. Photoproduction of Positive Mesons near Threshold. D. H. MILLER AND D. A. HILL, *General Electric Research Laboratory.*—π^+ mesons produced by passing the 235 Mev x-ray beam through a 6-in. diam, 4-in. deep hydrogen bubble chamber are being studied. To minimize electron background (a) low-energy quanta are preferentially scattered out of the beam by filtering through 80 g/cm² of LiH before final collimation; (b) the vacuum systems of the chamber, final collimator, and magnetic sweep field are integral; (c) the bubble chamber wall is provided with 2 in. diam, 0.008-in. Mylar beam entrance and exit windows. Measurements of range and angle

with respect to the x-ray beam are made for those mesons stopped within the chamber volume. For photons of 165 Mev, mesons with c.m. angles between 20° and 130° are observed; for photons of 180 Mev, mesons with angles between 130° and 165°. Analysis of 500 events (20% of the data) in terms of an angular distribution $a\eta+b\eta^2\cos\theta$, with $\eta=p_\pi/mc$, yields a value of $b/a=-0.2\pm0.2$. Results of the complete analysis will be presented.

J5. Photoproduction of π^0 Mesons from Hydrogen near Threshold. D. A. Hill and D. H. Miller, *General Electric Research Laboratory*.—Using the bubble chamber described previously,[1] we are studying the photoproduction of π^0 mesons in hydrogen by measuring the angle and range in liquid hydrogen of the recoil proton. The method permits us to observe meson angles between 30° and 135° (in c.m. system) at 220 Mev gamma-ray energy and 95° to 135° at 175 Mev. An analysis of 450 events (about $\frac{1}{4}$ of our data) is consistent with a total cross section varying as $(P_\pi)_{c.m.}^3$ but indicates an angular distribution more isotropic than $(5-3\cos^2\theta_{c.m.})$ below 200 Mev. More complete results will be given.

[1] D. H. Miller and D. A. Hill, Bull. Am. Phys. Soc. Ser. II, 2, 194 (1957), preceding abstract.

J6. Photoproduction of Charged π Mesons from Nuclei.* John R. Waters, *Cornell University* (sponsored by Robert R. Wilson).—The bremsstrahlung beam of the 1-Bev Cornell strong-focusing synchrotron has been used to study the photoproduction of positive and negative pions from several nuclei. The elements investigated were Be, C, Al, Ca, Cu, Sn, Pb, and U. The targets were placed at the focal point of a double-focusing magnet which selected the energy of the mesons counted in a 3-counter telescope. The production of 40 and 80 Mev π^+ and π^- mesons was observed at 35° to the direction of the γ-ray beam as a function of the maximum energy of the beam. Preliminary results at the lower meson energy and 800-Mev beam energy for the π^-/π^+ ratios are Be $=1.49\pm0.06$, C $=1.15\pm0.10$, Al $=1.16\pm0.11$, Ca $=0.92\pm0.11$, Cu $=1.45\pm0.15$. Further data at low energies will be presented and also at higher meson energies using a new strong-focusing magnet capable of analyzing 700 Mev π mesons. Absolute cross sections and excitation curves have been measured.

* Supported by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.

J7. Photoproduction of Multiple Mesons in Hydrogen.* W. M. Woodward, R. R. Wilson, and P. D. Luckey,† *Cornell University*.—The photoproduction of positive and negative mesons is being studied as a function of the photon energy, meson angle, and meson energy. Using the x-rays from the Cornell 1 Bev synchrotron, mesons are produced from a liquid hydrogen target. They are detected by means of magnetic deflection followed by a counter telescope. Preliminary results show a steeply increasing cross section for photon energies above 600 Mev. Typical results are the following cross sections which are given in units of 10^{-33} cm² per Mev per "Q" per steradian in the lab system: For 40 Mev mesons at 90° and with 810 Mev photons $\sigma_{\pi^+}=11.6\pm1.1$ and $\sigma_{\pi^-}=1.80\pm0.28$; at 35° and at energies of 825, 700, and 600 Mev σ_{π^-} is, respectively, 3.50 ± 0.46, 2.66 ± 0.35, and 0.96 ± 0.30. Plans are underway to measure the angular correlation between mesons in the multiple production process.

* Supported by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.
† Now at MIT.

J8. Diffusion Cloud Chamber Study of Multiple Photomeson Production in H_2 at the Cornell Synchrotron.* J. M. Sellen, G. Cocconi, V. T. Cocconi, E. L. Hart, and K. C. Rogers.—A 20-atmos hydrogen-filled diffusion cloud chamber operating in a magnetic field of 6 kilogauss has been placed in the 870-Mev bremsstrahlung beam of the Cornell synchrotron. Multiple photoproduction of π mesons has been observed. The events are analyzed in terms of the energy of the incoming photons, and of the energy and angular distributions of the secondary particles.

* Assisted by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.

J9. Production of Negative Pions in H_2 by 1.95 Bev Protons.* R. M. Lea,† H. L. Kraybill, and E. C. Fowler, *Yale University*.—$120\pi^-$ mesons, produced in inelastic p-p collisions, have been observed as a result of exposing the hydrogen-filled Brookhaven diffusion cloud chamber to the 1.95-Bev external proton beam at the cosmotron. An incident proton flux of about 500 protons per picture was made possible without a general loss of sensitivity by confining the incident protons to a narrow pencil by collimation and strong focusing. This pencil beam was passed through the center of the chamber's sensitive region about twice per minute. 8500 photographs were obtained, corresponding to a scanned path length in H_2 of about 1.3×10^5 g/cm². The cross section for the reaction $p+p\rightarrow p+p+\pi^++\pi^-$ is estimated to be two millibarns, after correcting for the masking effect of the pencil beam. The momentum spectrum and angular distribution of the π^- in the center-of-mass system will be discussed. We wish to acknowledge the generous help extended by the Brookhaven Laboratory staff; especially Dr. Ralph P. Shutt and other members of the cloud chamber group and also Dr. Rodney L. Cool.

* This work was supported in part by the U. S. Atomic Energy Commission.
† General Electric Research Fellow, 1956–1957.

J10. Scattering of 31-Mev Positive Pions from Carbon. Prabhakar P. Kane, *University of Rochester* (introduced by E. M. Hafner).—Positive π mesons of 33 ± 1.3-Mev energy were incident on a carbon target 0.49 g per cm square thick. Scattering of the pions was studied in transmission geometry at 70 and 120 degrees. Measurements were taken simultaneously at the two angles. The target was oriented so as to minimize the energy spread in the 120 degree scattering. Pulse-height analysis of the scattered pions at 120 degrees shows that both elastic scattering and scattering from the first excited state in carbon are present, the two contributions being approximately equal. This interpretation is consistent with a range analysis of the scattered particles. At 70 degrees, contribution of the first excited state to the scattering is small, certainly less than 20% of the elastic scattering. In view of these results, the elastic scattering cross section at 70 degrees is the same as that at 120 degrees, the value in each case being 4.2 ± 0.6 mb per steradian. Further measurements at other angles and using somewhat different techniques will also be presented.

J11. Pion Proton Differential Scattering Cross Sections at 40 Mev.* B. Rose and S. W. Barnes, *University of Rochester*.—We have remeasured the positive pion proton forward differential scattering cross section at 40 Mev under new low background conditions and find a value of $d\sigma/d\omega$ of 0.24 ± 0.03 mb/sterad at 45°. A measurement made at 120° which is at this writing not yet evaluated will be reported.

* This research was assisted by the U. S. Atomic Energy Commission.

J12. Interactions of 61 Mev π^+ Mesons in Deuterium.* A. M. Sachs, H. Winick, and B. A. Wooten, *Columbia University*.—Using methods previously described,[1] measurements have been made of the scattering and nonradiative absorption in liquid deuterium of 61 ± 3 Mev positive pions. For pions scattered with laboratory energy greater than 16 Mev the differential cross sections at 45°, 60°, 90°, 113°, 135°, and 150° in the laboratory system are 1.38 ± 0.15, 1.05 ± 0.09,

1.46 ± 0.09, 1.92 ± 0.12, 2.34 ± 0.13, and 2.38 ± 0.16 mb/sterad, respectively. Protons from nonradiative absorption $(\pi^+ + d \rightarrow p + p)$ fit the distribution $(0.25\pm0.03)+(1.03\pm0.08)\times\cos^2\theta$ mb/sterad in the center-of-mass system giving a total cross section for nonradiative absorption of 7.78 mb. From energy distributions of scattered mesons at each angle an estimate of the elastic contribution to the scattering may be obtained and compared to the impulse approximation.[3]

* This research was supported by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.
[1] Sachs, Winick, and Wooten, Bull. Am. Phys. Soc. Ser. II, 1, 350 (1956).
[2] R. M. Rockmore, Phys. Rev. 105, 256 (1957).

J13. Reaction $\pi^- + d \rightarrow n + n$ at High Energy.* W. A. LOVE† AND R. T. SIEGEL, *Carnegie Institute of Technology.*—Coincidence between two neutrons emitted in the above reaction have been observed at 190 Mev incident pion kinetic energy. Preliminary measurements were made with a D_2O-H_2O scatterer. The neutron counters are 9 in. diam by 6 in. thick plastic scintillators, each shielded by a $\frac{1}{2}$-in. thick lead radiator and a 10-in. diam anti-coincidence counter. Counting rates at 74° laboratory neutron angle (90° c.m. angle) are approximately those expected on the basis of neutron counter efficiency and known cross sections for the reaction $\pi^+ + d \rightarrow p + p$, to which the observed process is charge-symmetric. Angular correlation and other tests to verify the reaction identification will be described.

* This work was supported in part by the U. S. Atomic Energy Commission.
† National Science Foundation Predoctoral Fellow.

FRIDAY MORNING AT 9:30

Sheraton-Park, Continental Room

(V. L. SAILOR presiding)

Fission and Fissile Nuclei

K1. A Fission Fragment Mass Separator and the Nuclear Charge Distribution of Single Mass Fission Fragments. BERNARD L. COHEN AND CLYDE B. FULMER, *Oak Ridge National Laboratory.*—An energetic fission fragment passing through a gas changes its charge frequently because of electron capture and loss collisions with gas molecules. Its average charge, $\bar{e}$, is found to be proportional to velocity, so that magnetic deflection depends only on mass; thus, passing fission fragments through a gas-filled magnetic spectrograph gives mass separation. At low pressure the resolution is limited by the statistics of the electron capture and loss process; increasing the pressure to reduce this effect is eventually limited by energy loss effects. However, before this occurs, there is a range where resolution is limited by the nuclear charge distribution of single mass fragments. All of these effects were studied experimentally. The best resolution obtained for mass 91 or 97 fragments (with helium) was 3.5% of which 2.2% is the result of the nuclear charge distribution. The dependence of $\bar{e}$ on nuclear charge was studied. The result for the full width at half-maximum of the nuclear charge distribution of single mass fragments is 2.0 units. The best obtainable resolution from a mass separator is 3.2% corresponding to 4.5 mass units for light fragments. Several applications of this instrument will be described, and other possible applications will be suggested.

K2. Scintillation Pulse Height in CsI(Tl) *vs* Energy and Range in Various Materials *vs* Energy for Light and Heavy Fission Fragments. CLYDE B. FULMER AND BERNARD L. COHEN, *Oak Ridge National Laboratory.*—Light and heavy fragments from pile neutron fission of uranium-235 were magnetically separated and scintillation pulse heights in CsI(Tl) determined as a function of range in various metals and gases. Using the energy loss *vs* range data of Lassen, and Schmitt and Leachman,[1] curves were obtained for pulse height in the CsI(Tl) crystal *vs* energy for light and heavy fragments, also differential light output (dL/dx) *vs* rate of energy loss $(-dE/dx)$. dL/dx for fission fragments is more than twice as large as for 5 Mev alpha particles, and continues to increase monotonically with rate of energy loss throughout the range, contrary to the findings of Eby and Jentschke[2] for NaI(Tl). Using the total range in air data of Katcoff, Miskel, and Stanley,[3] complete range-energy curves were constructed for hydrogen, helium, air, argon, aluminum, nickel, silver, and gold.

[1] N. O. Lassen, Kgl. Danske Videnskabs. Selskab, Mat-fys. Medd. 24 (1949); H. W. Schmitt and R. B. Leachman, Phys. Rev. 102, 183 (1956).
[2] F. S. Eby and W. K. Jentschke, Phys. Rev. 96, 911 (1954).
[3] Katcoff, Miskel, and Stanley, Phys. Rev. 74, 631 (1948).

K3. Precision Thermal Fission Cross Sections by a New Method.* L. M. BOLLINGER, A. SAPLAKOGLU, C. COCEVA, R. E. COTE, AND G. E. THOMAS, *Argonne National Laboratory.*—In all previous absolute measurements of fission cross sections σ_f at 0.0253 ev, serious errors resulted from uncertainties in at least one of the following: fission foil thickness, value of a reference absorption cross section, energy distribution of incident neutrons. We have developed a new method which avoids all these difficulties. Neutrons from a chopper impinge on a metallic fissile foil with transmission near unity yet thick enough to be easily weighed. The fission rate R_f is $n\sigma_f F$, where F is incident flux and n is foil thickness; thus measurement of R_f and F gives σ_f. R_f is measured by detecting fission neutrons in large liquid scintillators which are insensitive to radiative capture events. Fission detection efficiency is determined by observing the fraction of counts in a fission ionization chamber which are coincident with counts in the liquid system. Flux is similarly measured. All transmitted neutrons are absorbed in B^{10} 120 cm away and γ rays from the $B^{10}(n,\alpha)Li^7$ reaction are detected in a NaI scintillator; detection efficiency is again determined by a coincidence method. Errors caused by instrumental instability are avoided by recording all rates simultaneously. Results from 0.01 to 0.2 ev which contain no known uncertainties greater than one percent will be given for U^{235}.

* Work performed under the auspices of the U. S. Atomic Energy Commission.

K4. Neutron-Induced Fission Cross Section for U^{233}, U^{235}, U^{238}, and Pu^{239} from 2 to 10 Mev.* R. K. SMITH, R. L. HENKEL, AND R. A. NOBLES, *Los Alamos Scientific Laboratory.*—The excitation curves for the neutron-induced fission cross section of U^{235} and U^{238} have been obtained for neutron energies from 2 to 10 Mev. The general features of the excitation curves appear to verify the shape predicted by N. Bohr in 1940.[1] The curves are essentially constant between 2.0 and 5.5 Mev neutron energy. Above this energy, the $(n,n'f)$

process begins and the cross sections rise to a higher constant value above 8.0 Mev. For U^{235} and U^{238}, measurements were made with a fission foil and a CH_2 foil, mounted back-to-back and irradiated in a neutron flux of variable energy using the $T(p,n)He^3$ and $D(d,n)He^3$ reactions as neutron sources. Fission fragments were detected in a parallel-plate ionization chamber and proton recoils were counted by a coincidence detector using two proportional counters and a crystal scintillator. By measuring the counting rate ratios of the foils and using the well-known cross section for (n,p) scattering, the fission cross sections were obtained. Corrections were made for the $D(d;n,p)D$ neutrons in the neutron energy region between 8 and 10 Mev. Neutron flux determinations had uncertainties of about 3%. The uncertainties in fission cross-section values are about 5%. The U^{233} and Pu^{239} fission cross sections were obtained by measuring ratios with U^{235} in a double ionization chamber.

* Work performed under the auspices of the U. S. Atomic Energy Commission.
[1] N. Bohr, Phys. Rev. **58**, 864 (1940).

K5. Spontaneous Fission Neutron Multiplicities.* ROBERT V. PYLE AND DONALD A. HICKS,† *University of California, Berkeley.*—It has been reported earlier[1] that the average number of neutrons per spontaneous fission of Cf^{252} decreases rapidly as the sum of the kinetic energies of the two fission fragments increases. A decrease in $\bar{\nu}$ with increasing kinetic energy also is observed when only one of the fragments is detected, a fact of importance to experimenters using fissionable material in a pulse detector as a neutron standard. For Cf^{252}, the 20% of the fissions having the lowest fragment energies give $\bar{\nu}=4.15\pm0.07$, and the 20% with the highest energies give $\bar{\nu}=3.02\pm0.07$ ($\bar{\nu}=3.82$ for all fission energies). Additional structure is observed at intermediate energies. Similar effects have been observed with other nuclides.

* This work was done under the auspices of the U. S. Atomic Energy Commission.
† Now at Boeing Airplane Company.
[1] Hicks, Ise, Pyle, and Choppin, Bull. Am. Phys. Soc. Ser. II, 1, 8 (1956).

K6. Calculations Concerning the Mass Distribution of Fission Products.* ROBERT L. W. CHEN AND PETER FONG, *Syracuse University.*—According to a statistical theory[1] the relative probability of a fission mode depends essentially on the total excitation energy of the two fission fragments. The original calculation of excitation energy based on an empirically corrected atomic mass formula has shown discrepancy in Pu^{240}. Newly available information on atomic masses has been used to repeat the previous calculations.[2] In the present work, Coryell's beta energetics,[3] Way and Wood's beta-energy systematics,[4] Hay and Newton's mass values,[5] and Levy's mass formula[6] are used for a number of fissioning nuclides. The results obtained for one single fissioning nuclide (Pu^{240}) are similar to one another in that the excitation energy curves all show one single peak in the asymmetric fission region and the peak widths are too narrow. The results also show that the heavy fragment peaks of several fissioning nuclides nearly coincide while the light fragment peaks shift apart in agreement with observed results.

* Supported in part by the National Science Foundation.
[1] P. Fong, Phys. Rev. **102**, 434 (1956); **89**, 332 (1953).
[2] P. Fong, Bull. Am. Phys. Soc. Ser. II, 1, 303 (1956).
[3] C. D. Coryell, Ann. Rev. Nuclear Sci. 2, 305 (1953).
[4] K. Way and M. Wood, Phys. Rev. **94**, 119 (1954).
[5] I. W. Hay and T. D. Newton, Atomic Energy of Canada Limited Document TPI-87 (July 1956).
[6] H. B. Levy, U. S. Atomic Energy Commission Document UCRL-4588 (November 30, 1955).

K7. Velocity Distribution of Fission Fragment Pairs from Cf^{252} and the Coincident Gamma-Ray Spectrum. J. C. D. MILTON AND J. S. FRASER, *Chalk River Laboratories.*—An automatic recording time-of-flight apparatus previously described[1] has been used to measure simultaneously the velocities of both fission fragments. A weightless source of Cf^{252} giving 3×10^4 fissions per min was deposited on a film of 5 $\mu g/cm^2$ of VYNS coated with 5 $\mu g/cm^2$ of gold.[2] With a flight path of 177 cm a counting rate of 5.5 cpm was obtained. The most probable total kinetic energy before neutron emission was found to be 181 ± 5 Mev from an analysis of 29 000 events. The most probable mass ratio was 1.34. The full width at half-maximum of the total kinetic energy distribution for the most probable mass ratio was 22 Mev. A *f-f* coincidence opens a gate and allows the gamma-ray pulse, if any, from the 4-in. diam $\times4$ in. NaI crystal placed three inches from the source, to reach the analyzer. In about 30% of all events a gamma pulse height greater than 200 kev is recorded. The analysis of the information on gamma-ray yields will be presented.

[1] J. S. Fraser and J. C. D. Milton, Bull. Am. Phys. Soc. Ser. II, **2**, 17 (1957).
[2] We wish to thank Dr. S. G. Thompson and Dr. T. Sikkeland of the University of California Radiation Laboratory, Berkeley, for the preparation of this source.

K8. Short-Lived Bromine and Selenium Nuclides from Fission.* J. E. SATTIZAHN, M. KAHN,† AND J. D. KNIGHT, *Los Alamos Scientific Laboratory.*—A 6.0 ± 0.2-min bromine activity has been found in fission products and in rubidium bombarded with *D-T* neutrons. Experiments with enriched Rb^{85} and Rb^{87} support its assignment as an isomer of Br^{84}. Beta- and gamma-scintillation counting with 100-channel pulse analysis indicate beta groups of 0.8 ± 0.1 Mev (~20%), 1.9 ± 0.2 Mev (~70%), and possibly 3.2 Mev (~8%), plus prominent gamma rays of 0.44 ± 0.01 Mev (60%), 0.88 ± 0.01 Mev (70%), 1.46 ± 0.02 Mev (60%), and 1.89 ± 0.03 Mev (20%). The U^{235} thermal fission yields of the 6.0-min Br^{84} and the 31.7-min Br^{84} are 0.019 ± 0.002% and 0.90 ± 0.04%, respectively. By rapid separation of selenium from fission products and subsequent milking of the bromine daughters the half-lives of Se^{84} and Se^{85} have been measured as 3.3 ± 0.2 min and 40 ± 4 sec, respectively. The 6.0-min Br^{84} does not appear to grow from selenium. The experiments also produced evidence for a 17 ± 3-sec selenium parent of a 1.0-min bromine activity which may be Br^{86} or Br^{87}.

* Work performed under the auspices of the U. S. Atomic Energy Commission.
† University of New Mexico.

K9. Gross Short-Lived Fission Product Gamma-Ray Spectra as a Function of Time after Fission. I. Time Dependence of Energy Groups. T. A. LOVE, W. ZOBEL, AND R. W. PEELLE, *Oak Ridge National Laboratory.*—Absolute experimental results will be presented for the photon decay rate of the gross U^{235} fission product mixture between 1.2 sec and 1500 sec after thermal fission for each of six photon energy groups covering the range between 0.28 and 5.0 Mev. Performance data on the spectrometer and time analyzer will also be given. The information extracted from this experiment will be discussed in relation to that previously available from theoretical estimates and from spectroscopic data obtained after chemical separations of specific radio-nuclides. The data were obtained from two- and three-crystal scintillation spectrometers which utilized the Compton and pair-production effects to obtain reasonable uniqueness of pulse-height response for monoenergetic gamma rays. Small (2, 7, or 15 mg) samples of (93%) enriched U^{235} were inserted in the Oak Ridge National Laboratory Graphite Reactor by the use of a pneumatic tube assembly, and similarly removed after bombardment periods as short as 0.7 sec. The bombardment time was chosen to be as short as possible compared to the waiting time before pulses were recorded. A forty-channel time analyzer, which featured successively widening time channels, was used to

obtain the time dependence of the photon intensity within each of the six energy groups. Three overlapping runs for each energy group were required to cover the entire time range.

K10. Gross Fission Product Gamma-Ray Spectra as a Function of Time after Fission. II. Energy Spectra at Fixed Times. W. Zobel, R. W. Peelle, and T. A. Love, *Oak Ridge National Laboratory.*—Experimental results will be presented for the gross fission product photon energy spectrum in the energy range from 0.28 to 5.4 Mev, measured at ten different times between 1.7 sec and 1550 sec after thermal fission. The detecting and recording equipment was essentially the same as that described in the preceding paper with additional timing equipment to allow for selected bombarding, waiting, and counting periods. These periods were chosen to avoid any bias against photons resulting from fissions occurring at the beginning of the bombardment. The analysis involved in the reduction of the raw data will be described, with particular attention to the correction for the nonuniqueness of the spectrometer pulse-height response to monoenergetic gamma rays. The results of this experiment will be compared with those described in the preceding paper. The total number of protons per fission and the total photon energy released per fission, each obtained by integration over the observed time and energy ranges, will be presented. These numbers will be compared with previous estimates.

K11. Gross Fission Product Gamma-Ray Spectrum. R. W. Peelle, T. A. Love, and W. Zobel, *Oak Ridge National Laboratory.*—The gamma spectrum of the gross U^{235} fission product mixture has been measured using a continuous fuel belt having a minimum rotation period of about 1.2 sec. At one end of its orbit, the fuel belt was exposed to thermal neutrons from the reflector of the Oak Ridge National Laboratory Graphite Reactor; at the other end the belt was observed by the collimator of a multiple crystal scintillation spectrometer. Prompt radiation originating at the points of fission was prevented from entering the collimator by water and lead shielding interposed within the circumference of the belt. The belt was rotated for a few hours before data were taken in order to provide approximate equilibrium of the long-lived gamma-ray emitters, and the spectrum during continued rotation was measured between 0.36 Mev and 5.8 Mev, using Compton and pair scintillation spectrometers similar to those described in the immediately preceding papers. The resulting spectrum is seriously biased against gamma-ray emitters with half-lives longer than 1 hr or shorter than 0.4 sec. The estimated standard error in the absolute normalization of the spectrum is 20–25%, based largely on difficulty in the determination of the fission rate in the fuel belt.

K12. Reactions of Uranium with 3-Bev Protons.* B. D. Pate and G. Friedlander, *Brookhaven National Laboratory.*—The formation of protactinium, astatine, and polonium nuclides in the bombardment of natural uranium with 3-Bev protons has been studied. Preliminary values for the formation cross sections (in mb) are given in Table I. The protactinium cross sections are lower by factors of 2 to 4 than those at 340 Mev[1]; this may indicate that, with increasing bombarding particle energy, fission competes with particle evaporation to a greater extent, reducing the yields of these products. If the ratio of fission width to nucleon evaporation width increases with increasing excitation energy as suggested by these and other data and by theoretical considerations,[2] the observed formation cross sections for Po and At are most difficult to rationalize in terms of spallation processes, and alternative mechanisms will be considered.

TABLE I.

Po^{206}	At^{209}	At^{211}	Pa^{227}	Pa^{228}	Pa^{229}	Pa^{231}	Pa^{230}	Pa^{224}	Pa^{225}
1.0	0.9	0.5	0.17	0.64	2.4	3.3	15	12	8.7

* Research performed under the auspices of the U. S. Atomic Energy Commission.

[1] M. Lindner and R. N. Osborne, Phys. Rev. 103, 378 (1956).

[2] B. T. Gellikman, "Proceedings of the international conference on the peaceful uses of atomic energy," Paper P/652, Vol. 2, p. 201 (1956).

K13. On the Alpha Decay of Pu^{239}. J. R. Huizenga, D. W. Engelkemeir, and F. S. Tomkins, *Argonne National Laboratory.*—The favored α decays in odd A nuclei populate the rotational band for which the orbit of the last odd nucleon remains unchanged,[1] and on this basis one expects the 5.150-Mev α particles of Pu^{239} (ground state spin $=\frac{1}{2}$) to populate an excited state in U^{235} of $I=\frac{1}{2}$ (ground state spin $=\frac{7}{2}$). On the assumption that the energy spacing between the $\frac{1}{2}+$ and $\frac{7}{2}-$ levels in U^{235} is small (a few kev), and hence the lifetime of the transition long, we separated about 10^2 μg of U^{235} which had grown into a ten-year old Pu^{239} sample for a spin determination. The spectrum examined in an electrodeless discharge, was the same as that of natural U^{235} except for a 20% U^{238} contamination, thereby enabling us to place an upper limit on the half-life of a possible ($I=\frac{1}{2}$) excited state of 0.5 year. Scintillation and proportional counting experiments rule out all possible radiations following the 5.150-Mev α particles except γ rays converting in the N shell or beyond. The recently observed 2-kev conversion electrons,[2] if interpreted as a 3-kev γ ray converting in the N and O shells, possibly de-excite the $\frac{1}{2}+$ level of U^{235} to the ground state, $I=\frac{7}{2}-$.

[1] Bohr, Fröman, and Mottelson, Kgl. Danske Videnskab. Selskab, Mat. fys. Medd. 29, No. 10 (1955).

[2] K. N. Shlagin, Soviet Phys. (JETP) 3, 663 (1956).

K14. $U^{238}(n,2n)U^{237}$ Cross Section from 6 to 10 Mev.* J. D. Knight, R. K. Smith, R. A. Nobles, and B. Warren, *Los Alamos Scientific Laboratory.*—The cross section for the $U^{238}(n,2n)U^{237}$ process has been measured for neutron energies from 6 to 10 Mev. Small pellets of U^{238} were irradiated for 2 to 4 hr in $D(d,n)He^3$ neutron fluxes of $\sim 10^9$ neutrons/cm^2/sec. Total fission and $n,2n$ events were measured by radiochemical analysis for Mo^{99} and U^{237}, respectively. (The U^{239} from the n,γ process was allowed to decay to negligible levels before the U^{237} analyses were started.) The $n,2n$ cross sections were then obtained by multiplying the measured $n,2n$/fission ratios by the U^{238} fission cross sections previously measured at this laboratory. The Mo^{99} production per U^{238} fission was determined at 7 and 9 Mev by measuring directly the number of fissions in a thin foil exposed back-to-back with a thick sample which was then analyzed for Mo^{99}.

E_n(Mev)	$\sigma_{n,2n}$(barns)	E_n(Mev)	$\sigma_{n,2n}$(barns)
6.00 ± 0.11	0.00 ± 0.03	7.90 ± 0.08	1.12 ± 0.11
6.61 ± 0.20	0.07 ± 0.04	8.50 ± 0.07	1.20 ± 0.12
6.82 ± 0.10	0.29 ± 0.03	9.61 ± 0.10	1.35 ± 0.13
7.10 ± 0.15	0.49 ± 0.05	10.0 ± 0.11$_5$	1.40 ± 0.14
7.38 ± 0.14	0.81 ± 0.08		

* Work performed under the auspices of the U. S. Atomic Energy Commission.

FRIDAY MORNING AT 9:30

Sheraton-Park, Caribar-Mural Room

(W. A. NIERENBERG presiding)

Optical and X-Ray Spectra; Molecular-Beam Experiments

KA1. $M_{2,3}$ Absorption Spectra of the Elements Cr to Ge.* D. H. TOMBOULIAN, D. E. BEDO, AND W. M. NEUPERT, *Cornell University.*—Recent investigations of the heretofore unexplored $M_{2,3}$ spectra of Cr, Mn, Ga, and Ge, together with supplementary measurements on Co, Ni, Cu, and Zn, make it possible to survey the energy dependence of the absorption coefficient, $\mu(E)$, for the entire sequence of nine elements (Cr to Ge) in the vicinity of the $M_{2,3}$ edge. The $M_{2,3}$ discontinuity, which corresponds to the onset of $3p \rightarrow$conduction band transitions, appears essentially as an unresolved feature above a high background absorption caused by valence band electrons. In each case the energy (in ev) corresponding to the midpoint of the change in absorption at the edge is observed to be: chromium 43.2, manganese 49.8, iron[1] 54.7, cobalt 59.8, nickel 65.8, copper 75.7, zinc 88.3, gallium 103.5, and germanium 123.3. A comparison of these values with existing emission data will be presented. On the high-energy side of the edge, the $\mu(E)$ curves show a number of fluctuations. The paper which follows summarizes the measurements pertaining to the secondary structure.

* Supported by the Office of Ordnance Research, U. S. Army.
[1] D. E. Carter and M. P. Givens, Phys. Rev. **101**, 1469 (1956).

KA2. Secondary Structure in the $M_{2,3}$ Absorption Spectra of the Elements Cr to Ge.* D. E. BEDO† and D. H. TOMBOULIAN, *Cornell University.*—A study of the soft x-ray absorption by thin foils of the elements extending from Cr to Ge has revealed the presence of secondary structure on the short wavelength side of the $M_{2,3}$ edge. The observed spectral positions of various absorption maxima (measured in ev from the edge) are listed below. The peak positions are compared with available data[1,2] for characteristic energy losses suffered by electrons in passing through foils of the same materials. Possible correlations are indicated by including the loss values in parentheses. Chromium, 10.3(9.7), 18.3, 22.7(21.8), 26.7(26.0); manganese, 2.5, 6.7, 10.1(9.9), 16.6, 17.7, 21.6(22.1), 28.2; cobalt, 4.5, 6.7(5.7), 11.7, 18.0(18.3); Nickel, 6.2(6.0), 11.7(12.5), 18.2(17.6), 24.7(23.4), 39.2, 47.2(47.0); copper, 8.8, 14.3, 19.3(20.3), 30.3, 36.8; zinc, 5.7(5.7), 11.2(9.9), 16.7(17.0), 23.2(23.0), 29.2, 39.7, 48.2, 56.7; gallium, 13.5, 21.5, 25.0, 38.5; germanium, 14.7(16.0), 28.7(30.0), 36.2(35.0).

* Supported in part by the Office of Ordnance Research, U. S. Army.
† Corning Glass Foundation Fellow.
[1] Marton, Leder, and Mendlowitz, *Advances in Electronics* (Academic Press, Inc., New York, 1955), Vol. VII, pp. 183–238.
[2] Leder, Mendlowitz, and Marton, Phys. Rev. **101**, 1460 (1956).

KA3. Optical Absorption of Solid Argon in the Far Ultraviolet.* J. R. NELSON AND P. L. HARTMAN, *Cornell University.*—An absorption peak centered at 1420 A (8.75 ev) is observed in solid argon. At the beginning of this work reflectivity measurements on solid argon in a liquid helium cryostat[1] only slightly modified were tried. Unfortunately, the over-all level of reflectivity of the solid argon was low, and no absorption peaks are discernable. Therefore, an opacity measurement requiring four measured values at each wavelength using a LiF substrate at about 8°K was attempted. An opacity peak at 1420 A was observed by this method. This peak has also been observed by a technique of solidifying the argon on a thin sodium salicylate[1] phosphor screen which has been put on a good thermally conducting crystal. Use of this technique eliminates need for a far ultraviolet transmitting substrate, and also a substrate opacity need not be measured, thereby necessitating only two measured values at each wavelength. Possible mutiplet structure in the 1420 A peak is being investigated, and the apparatus is being further modified to make measurements at wavelengths shorter than 1200 A to which we have been limited because of the necessity[1] of a LiF window in the cryostat.

* Supported in part by the Office of Naval Research.
[1] Hartman, Nelson, and Siegfried, Phys. Rev. **105**, 123 (1957).

KA4. Progress in the Analysis of the Te II Spectrum. M. BERNARDA HANDRUP,* *O. S. F.*, AND J. E. MACK, *University of Wisconsin.*—The Te II spectrum has been extended with the help of new ultraviolet line measurements on plates furnished by S. Avellén, Lund University, and of excellent new Zeeman effect data from Vander Sluis and Griffin, Oak Ridge National Laboratory. About 300 lines have been classified. The number of known levels[1] has been increased to 29 odd and 38 even ones plus several tentative ones, principally odd ones around 135 000 to 149 000°K. A few approximate LS assignments seem possible for levels of $5s^25p^3$ and $5s5p^4$, but intermediate coupling makes such assignments meaningless for most of the levels. The g sums for the almost complete configuration $5s^25p^36p$ indicate the absence of appreciable configuration interaction, but except for $5s^25p^3$, $5s^25p^36p$, and part of $5s5p^4$, interactions seem to be too strong to allow unique configuration assignments. No series are known, but the ionization potential has been estimated at 18.6 ± 0.4 v from the spacing of successive level groups, in good agreement with Finkelnburg and Humbach's[2] screening-constant value of 18.8 ± 0.5 v. Work on the spectrum is continuing.

* Now at Alverno College.
[1] Mack, Murakawa, Rose, Pick, and van den Bosch, Phys. Rev. **83**, 654 (1951).
[2] W. Finkelnberg and W. Humbach, Naturwissenschaften **42**, 35 (1955).

KA5. Cross Sections for Excitation of Nitrogen by Protons of a Few Kev Energy.* N. P. CARLETON, *Harvard University.*—Cross sections for excitation by proton impact are necessary for quantitative interpretation of auroral spectra. These are being measured for excitation of nitrogen by protons of a few kev energy, using interference filters to select various spectral features and a photomultiplier to detect the light emitted. The light detection apparatus is calibrated against a standard tungsten filament lamp. The measured cross sections are not for excitation of a given molecular energy level, but rather for a process resulting in the emission of one photon in a given transition. Provisional values for cross sections for 2.5-kev protons according to this definition follow: for the (2,0) band of the Meinel system of N_2^+, $\lambda 7850$, 2×10^{-18} cm^2; for a group of N I lines $3p^4P^0 - 3s^4P$, $\lambda 8185$–8216, 0.9×10^{-18} cm^2. For the first positive system of N_2 the cross section should be zero, since the excitation by protons is forbidden. The value zero is consistent with present data, which indicate an upper limit of 8×10^{-20} cm^2 for the (4,2) band of this system, $\lambda 7500$. Fast neutral H atoms, formed through charge exchange, do excite this band, however, with a cross section of 1×10^{-17} cm^2. Measurements of the energy dependence of these cross sections and of excitation of other features in N_2, O_2, and H_2 are in progress.

* This work was partially supported by the U. S. Air Force Cambridge Research Center.

KA6. Isotope Shift in the Atomic Spectrum of Carbon.* C. R. BURNETT, *Pennsylvania State University.*—Further measurements of the $C^{13}-C^{12}$ isotope shift in C II and C III have been obtained.[1] In addition, the $C^{14}-C^{13}$ isotope shifts have been similarly observed for these transitions using a sample of $BaCO_3$ enriched to 38% C^{14}. The observed shifts are ($1K=1\ cm^{-1}$):

		$C^{13}-C^{12}$	$C^{14}-C^{13}$
C III	$2s2p\ {}^1P_1-2p^2\ {}^1D_2$	$+1.05\ \pm0.03$ K	$+1.96\pm0.05$K
C II	$2s2p^3\ {}^3P_2-2p^2\ {}^3P_1$	$+0.96\ \pm0.02$ K	$+1.76\pm0.05$K
	$2s2p^3\ {}^3P_1-2p^2\ {}^3P_0$	$+0.97\ \pm0.03$ K	$+1.80\pm0.05$K
	$2s2p^3\ {}^5S_2-2s3p\ {}^5P_3$	-0.612 ± 0.002K[3]	-1.20 ± 0.05K
	$2s2p^3\ {}^5S_2-2s3p\ {}^5P_2$	-0.623 ± 0.003K	-1.12 ± 0.05K

The positive sign indicates that the heavier isotope is shifted to higher wave numbers. The errors listed are based on the random errors in measurement. It is suspected that systematic errors due to weak background lines may also be present. The ratios of observed shifts in the first three lines listed agree with mass effect predictions to within experimental error as found also in C I.[3]

* Research supported by Research Corporation.
[1] C. R. Burnett, Phys. Rev. **80**, 494 (1950).
[2] C. R. Burnett, Phys. Rev. **99**, 623(A) (1955).
[3] J. R. Holmes, J. Opt. Soc. Am. **41**, 360 (1951).

KA7. Isotope Shifts in the MoI Spectrum.* R. H. HUGHES, *University of Arkansas.*—The isotope shift in MoI $4d^55s^2\ {}^6D_4-4d^55p\ {}^6P_3^0$ transition at $\sigma=16\,577$ kaysers ($\lambda=6031$ A) has been studied in the hollow cathode spectrum from enriched even isotopes with a Fabry-Perot interferometer. The 94−92, 96−94, 98−96, 100−98, and 100−92 shifts in millikaysers are −25.6, −18.5, −12.0, −26.0, and −82.9, respectively. The minus sign indicates a shift in the field effect direction. The estimated limit error of the measurements is ±1.5 mK. The direction of the variation in the shifts was predicted by the position of the first excited states and the electric quadrupole transition probabilities as measured by Coulomb excitation[1] when these quantities are related to the isotope shift through the intrinsic deformation of these even-even nuclei. The magnitude of these variations is smaller, however, than would be expected in terms of the deformation parameters as calculated by Heydenburg and Temmer.[1]

* Supported by the U. S. Air Force through the Air Force Office of Scientific Research of the Air Force Research and Development Command.
[1] N. P. Heydenburg and G. M. Temmer, Ann. Rev. Nuclear Sci. **6**, 77 (1956).

KA8. Radio-Frequency Spectrum of Hydrogen Deuteride.* W. E. QUINN, J. M. BAKER, J. T. LA TOURRETTE, AND N. F. RAMSEY, *Harvard University.*—The molecular beam magnetic resonance method has been utilized to observe the radio-frequency spectrum of the HD molecule in the first rotational state to a considerably higher precision than the original investigation.[1] Measurements were made on the rotational spectrum, the deuteron nuclear spectrum, and the proton nuclear spectrum in applied magnetic fields of sufficient intensity to decouple the angular momenta concerned. The observed spectra are in agreement with a strong field ninth-order perturbation calculation. From an analysis of these spectra with the aid of perturbation theory, the rotational magnetic moment and following interactions are evaluated: the deuteron rotational interaction; the proton rotational interaction; the deuteron-proton spin-spin interaction; the deuteron quadrupole interaction; and the diamagnetic interaction. The greater accuracy of the present values is attributed mainly to the following: the use of a homogeneous field ten times longer than the previous one[1]; the application of the separated oscillatory field method; the use of higher precision frequency measuring equipment; and the development and use of an electron bombardment ionizer as a detector.

* This work was supported in part by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.
[1] Kellogg, Rabi, Ramsey, and Zacharias, Phys. Rev. **57**, 677 (1940); N. F. Ramsey, Phys. Rev. **58**, 226 (1940).

KA9. Theoretical Shapes of Molecular Beam Resonances. NORMAN F. RAMSEY, *Harvard University.*—A Univac computer program has been developed for the calculation of the shapes of molecular beam resonances under a wide variety of circumstances. The program is applicable to systems involving simultaneous transitions between two or three different energy levels and to cases where the fixed fields, the amplitudes of the oscillatory fields, and the phases of the oscillatory fields vary arbitrarily throughout the transition region. The calculation is applicable to systems perturbed at as many as nine different frequencies simultaneously and to arbitrarily determined molecular velocity distributions. The problems so far computed include molecular beam resonances with three separate oscillatory fields, resonances with four separated oscillatory fields, and resonances with a gradually applied single oscillatory field. Slides showing the theoretical resonance shapes for these and other cases will be shown.

KA10. Hyperfine Structure of Thallium-204.* G. O. BRINK, J. C. HUBBS, W. A. NIERENBERG, AND J. L. WORCESTER, *University of California, Berkeley.*—The hyperfine structure interval of 4-yr Tl^{204} has been measured by the atomic beam magnetic resonance method; the result is $\Delta\nu=732\pm5$ Mc in the ground $^2P_{\frac{1}{2}}$ state of thallium. Previous measurements have shown that the spin of this nuclide is 2.[1] The hyperfine structure determination is made from observations on the transition ($F=5/2,\ m_F=-5/2\leftrightarrow F=5/2,\ m_F=-3/2$) at five magnetic fields between 15 and 266 gauss. The nuclear magnetic moment inferred from the measured hyperfine structure of Tl^{204} and from the measured magnetic moments[2] and hyperfine structures[3] of Tl^{203} and Tl^{205} is 0.0894 ± 0.0020 nm. The effect of this magnetic moment of the frequency of the observed transition is so small that no assignment can as yet be given for the sign of the magnetic moment.

* This work was done under the auspices of the U. S. Atomic Energy Commission.
[1] Brink, Hubbs, Nierenberg, and Worcester, Bull. Am. Phys. Soc. Ser. 2, **1**, 343 (1956).
[2] H. L. Poss, Phys. Rev. **75**, 600 (1949).
[3] A. Berman, Phys. Rev. **86**, 1005 (1952).

KA11. Nuclear Spin of Cu^{61} (3.3 hr).* W. A. NIERENBERG, H. A. SHUGART, AND H. B. SILSBEE, *University of California, Berkeley.*—The nuclear spin of 3.3-hr Cu^{61} has been measured and found to be $\frac{3}{2}$ by the atomic beam nuclear magnetic resonance method using the apparatus described in reference 1. The radio-isotope was prepared by the $Co^{59}(\alpha,2n)Cu^{61}$ reaction in the Berkeley 60-in. cyclotron. No chemistry was performed on the Co foil since it was found that an atomic beam of Cu could be formed by heating the target foil in the atomic beam oven. Normalization of the spin exposures was accomplished by exposures taken with the magnetic fields on and the stop wire removed. This permitted the insufficiently deflected portion of the beam to reach the detector. An auxiliary Cs^{133} beam served to calibrate the transition magnetic field (C field). The measure spin of $\frac{3}{2}$ for Cu^{61} is consistent with the measured spins of $\frac{3}{2}$ for Cu^{63} and Cu^{65}.[2] On the basis of the simple shell model the spin arises from the odd $p\frac{3}{2}$ proton.[3]

* This work was supported by the Office of Naval Research and the U. S. Atomic Energy Commission.
[1] Hobson, Hubbs, Nierenberg, Silsbee, and Sunderland, Phys. Rev. **104**, 101 (1956).
[2] R. Ritschl, Z. Physik **79**, 1 (1932).
[3] M. G. Mayer and J. H. D. Jensen, *Elementary Theory of Nuclear Shell Structure* (John Wiley and Sons, Inc., New York, 1955), p. 77.

FRIDAY MORNING AT 9:30

NBS, East Building

(J. BARDEEN presiding)

Solid-State Physics III, Mostly Theory

L1. Vibrational Spectra of Diamond Cubic Crystals. D. E. EASTWOOD, *Illinois Institute of Technology*, AND J. R. MADIGAN, *Hoffman Semiconductor Division.*—Improved vibrational spectra have been calculated for diamond and silicon, using the Born-von Karman method and the same force constants used by Smith[1] and by Hsieh.[2] In the earlier work, calculation of the vibrational frequencies was carried out for twenty-nine wave vectors, which by symmetry give the frequencies corresponding to 596 points in the first Brillouin zone. The present work includes calculations for 148 and 421 wave vectors, corresponding respectively to 4408 and 14 508 points in the first Brillouin zone. Specific heat calculations based on the new spectra will be reported.

[1] H. M. J. Smith, Trans. Roy. Soc. (London) **A241**, 105 (1948).
[2] Yu-Chang Hsieh, J. Chem. Phys. **22**, 306 (1954).

L2. Vibration Spectra of Face-Centered-Cubic Lattices. W. C. OVERTON, JR., *U. S. Naval Research Laboratory.*—Extensive machine calculations, using NRL's NAREC, of the vibration spectra of f.c.c. lattices based on the two force-constant central-force model have been carried out for 11 values of γ/α in the range $-0.25 \leq \gamma/\alpha \leq 0.25$. The calculations involved some 15 800 solutions of the secular determinant along 70 different k-vector directions in 1/48th the Brillouin zone for each value of γ/α. Very accurate values of $k^2 dk/d\nu$ were obtained from solutions at some 3640, 3500, and 2660 points, respectively, for the longitudinal and two transverse branches. The resulting $G(\nu)$ values are fairly accurate (better than 1% at low frequencies) for constant frequency surfaces that enclose the origin of k space, but some of the higher frequency surfaces that are concave outward, less accuracy was obtained because of the finite size of the solid angle involved in the integration. Critical points in the [100] and [110] planes have been determined and their relation to the whole family of spectra will be shown. For $\gamma/\alpha > 0.14906$ there are two saddle points separated by an island in each quadrant of the [100]–[001] plane. For all $\gamma/\alpha < 0.14906$ . . ., these coalesce into a single saddle point lying in the [101] direction.

L3. Vibration Spectrum of Vanadium by Neutron Spectrometry. A. T. STEWART AND B. N. BROCKHOUSE, *Chalk River Laboratories.*—The change in energy of neutrons inelastically scattered through 90° by a vanadium specimen has been measured using the Chalk River slow neutron chopper and time of flight apparatus. A subtraction technique using matched Pb and Be filters effectively selected incident neutrons in the energy range $3\text{–}5 \times 10^{-3}$ ev. Scattered neutrons were transmitted in bursts by the 7200 rpm, 6°, chopper, traversed a 4.5-m flight path, and were counted in a bank of 12 BF_3 counters. The times of flight of these neutrons were converted to pulse amplitudes and recorded by a 30-channel kick-sorter. Experiments were performed at room temperature, and also at liquid nitrogen temperature to eliminate the contribution from elastic scattering. From the resulting inelastic scattering the vibration spectrum of the normal modes can be obtained.[1] We find that the vibration spectrum of vanadium for small wave numbers is approximately Debye ($N \propto q^2$). Under present resolution it appears to have two just resolved peaks at frequencies about 5.1×10^{12}/sec and 6.8×10^{12}/sec and shows a sharp cutoff at $\nu = 7.8 \pm 0.3\ 10^{12}$/sec ($\theta = 374$°K). These results are consistent with previous work of Brockhouse[2] but not with work of Carter, Hughes, and Palevsky.[3]

[1] G. Placzek and L. Van Hove, Phys. Rev. **93**, 1207 (1954).
[2] B. N. Brockhouse, Can. J. Phys. **33**, 889(L) (1955).
[3] Carter, Hughes, and Palevsky, Phys. Rev. **104**, 271(L) (1956).

L4. Interaction between Electrons and Lattice Vibrations in Metals. R. P. SINGH, *National Research Council, Canada.*—Bardeen[1] tried to calculate the resistance of a pure metal which results from the interaction of the electron waves with the vibrations of the lattice. The perturbation resulting from the elastic lattice waves, which is responsible for the transitions between the electronic states, was determined in a self-consistent manner by calculating the change in the self-consistent field of the valence electrons when the crystal is distorted. The electron-lattice interactions were treated in the Hartree approximation. The matrix elements for the scattering of electrons by lattice waves were found to be small. If one does not take the change in the self-consistent into account the matrix elements are rather large. Recently Bardeen and Pines[2] have discussed this problem in the light of the Bohm and Pines theory but the result essentially does not go beyond those given by Bardeen in his 1937 paper. This problem will be discussed here in the light of Brueckner theory and the results discussed.

[1] J. Bardeen, Phys. Rev. **52**, 688 (1937).
[2] J. Bardeen and D. Pines, Phys. Rev. **99**, 1140 (1955).

L5. Effect of Order upon Longitudinal Lattice Vibrations in a Two-Dimensional Binary Alloy. J. C. BRADLEY, *RIAS* (introduced by G. Groetzinger).—The maximum frequency, ω_{max}, of the longitudianl lattice vibrations has been calculated for a square A-B lattice in the ordered and completely disordered states using a particular configuration in the latter case. This choice yields a periodic structure in the disordered state with the unit cell containing eight particles. Considering central and noncentral nearest neighbor interactions an eighth-order secular determinant was obtained. In applying Blackman's criterion to find the upper limit of the frequency spectrum it was observed that the effect of the off-diagonal elements for the disordered state was negligible—a feature that greatly facilitated the calculations. The difference $\Delta\omega_{max}^2$ between the values of ω_{max}^2 for the ordered and disordered states was found to be $\Delta\omega_{max}^2 = -\epsilon_1/M_A + \epsilon_2/M_B$, where the M's are the masses and the ϵ's are linear combinations of the force constants. Assuming the "longitudinal Debye temperature" for the three-dimensional lattice to be equal to $\hbar\omega_{max}/k$ this result should indicate the effect of disordering on the ideal resistivity as given by Gruneisen's formula.

L6. Electronic Energy Bands in Cesium.* E. L. HAASE AND J. CALLAWAY, *University of Miami.*—The orthogonalized plane-wave method is employed for a calculation of electronic energy levels in cesium, using a crystal potential with exchange adapted from that given by Sternheimer.[1] The core functions are obtained for that potential by numerical integration. S-, P-, D-, F-like bands for the four points of highest symmetry in the Brillouin zone are computed. The lowest energy level is found to be in good agreement with the value obtained by the cellular method. The results are compared with the energy levels of sodium and potassium, with the free electron approximation and Wigner's analysis of the P and D bands for the body-centered-cubic lattice.

* Supported by the Office of Naval Research.
[1] R. M. Sternheimer, Phys. Rev. **78**, 235 (1950).

L7. Relativistic Corrections to the Cohesive Energy of Cesium.* JOSEPH CALLAWAY AND R. D. WOODS, *University of Miami.*—The quantum defect method has been extended

to include relativistic effects in the calculation of the cohesive energies of the alkali metals. A relativistic formula for the effective mass was derived from the Dirac equation for one particle in a periodic potential. The result has the same form as Bardeen's expression, except that Schrödinger wave functions are replaced by large components of solutions of the Dirac equation and a combination of P functions of $j=\frac{1}{2}$ and $j=\frac{3}{2}$ is used. The ordinary quantum defect method contains all important relativistic corrections for the lowest state of a valence electron. The relativistic effective mass formula can be evaluated using the standard method, but different quantum defects must be obtained for P states of $j=\frac{1}{2}$ and $j=\frac{3}{2}$. This was done for cesium. The exact value of the correction is somewhat uncertain because of difficulties in extrapolation of the quantum defect to the energies of interest. The effect appears to change the cohesive energy 1% or less.

* Supported by the Office of Naval Research.

L8. Energy Difference between Hexagonal and Cubic Metals. G. L. HALL* AND J. S. PLASKETT, *University of Virginia.*—The energy of a stacking fault in a low valency ($\ll\pi\sqrt{\frac{3}{2}}$) cubic crystal has recently been calculated.[1] It therefore seemed of some interest to make a calculation, with the same approximations, of the hexagonal-cubic energy difference. This energy difference, regarded as an energy per fault, is in very close agreement with the single fault calculation. The comparison is restricted to valencies $<\pi\sqrt{\frac{3}{11}}$ so that the Fermi surface does not cut the "second-order" energy gap in the hexagonal crystal. The most important result, however, is that the single fault calculation is probably useless. In making the calculation it was necessary to use a discontinuous potential across the fault boundary and for comparison the same potential was used in the hexagonal calculation. If, on the other hand, a continuous potential is used the hexagonal-cubic energy is radically changed, even in sign.

* Now at Westinghouse Research Laboratory.
[1] R. W. Attree and J. S. Plaskett, Phil. Mag. Ser. 8, 1, 855 (1956).

L9. Sommerfeld Model and the Heat of Solution of an Alloy. W. G. HENRY, *National Research Council, Ottawa.*—The Sommerfeld model of an alloy is treated both by first-order perturbation theory and by an approximate second-order perturbation method initially due to Lennard-Jones.[1] The first-order treatment gives no terms indicating the formation of a solution. The second-order treatment yields a term which is negative when either species B is dissoved in species A or vice versa and is identifiable as a contribution to the partial molar heat of solution at zero concentration. The charge accumulation is calculated from the approximate first-order perturbed wave function. The displacement and the change of the width of the band are calculated. The problem of the polyvalent solute is discussed.

[1] J. E. Lennard-Jones, Proc. Roy. Soc. (London) **A129**, 598 (1930).

L10. Three-Constant Theory of Impurity Diffusion on Grain Boundaries. W. SHOCKLEY, J. HOERNI, AND C. S. ROBERTS, *Shockley Semiconductor Laboratory.*—Consider a grain boundary attractive to solute atoms containing the plane $x=0$ in a cubic crystal with dilute solute concentration $C(x,y,z,t)$. Consider a volume V of crystal with $C=C_0=$constant which contains an area A of grain boundary. Then the number of impurity atoms in V is C_0V+C_0AW where W is the *effective width*. If y and z are suitably rotated about x axis, then a concentration $C(x,y,z,t)=-(G_yy+G_zz)$ in the bulk produces the usual diffusion current density $F_{y,z}=D_LG_{y,z}$ plus extra currents of G_yD_yW and G_zD_zW per unit length in the boundary which define *boundary diffusion constants* D_y and D_z. The density of extra atoms per unit area may be written as $C_B(y,z,t)W$,

$$\frac{\partial}{\partial t}C_B=D_y\frac{\partial^2C_B}{\partial y^2}+D_z\frac{\partial^2C_B}{\partial z^2}+\frac{D_L}{W}(C_{+x}'-C_{-x}'),$$

where C_B must equal $C(x,y,z,t)$ as $x\to0$ on both sides, and $C_{\pm x}'$ are the limits of $\partial C/\partial x$ as $x\to0$ from the $\pm x$ axis.

L11. Thermal Energy Neutron Scattering Employing Einstein Model.* R. M. DELANEY, R. R. BOEDEKER, AND A. H. WEBER, *Saint Louis University.*—The Einstein model is applied to the scattering of thermal energy neutrons by atoms in a crystal lattice. Exact expressions are developed for the coherent elastic and inelastic cross sections. Using empirically determined Einstein temperatures, calculations of the total cross section as a function of temperature and neutron energy are made for below Bragg cut-off scattering of neutrons by beryllium, magnesium, and aluminum, and comparison is made with experiment. The results show the Einstein model to be valid for these substances for room temperature and above; and that as the temperature decreases, the Einstein model fails. Using the Einstein temperatures as determined by cross-section measurements, the Young's moduli are calculated for the three substances with reasonable agreement with actual values.

* Work supported by the Office of Ordnance Research.

L12. X-Ray Study of Textural Stresses in Two-Phase Alloys. C. J. NEWTON AND H. C. VACHER, *National Bureau of Standards.*—F. Laszlo[1] developed a quantitative theory of internal stresses in two-phase alloys whose microconstituents differed in their coefficients of thermal expansion. Although Laszlo did not believe that these textural stresses would be revealed by x-ray measurements, we have succeeded in detecting them in the carefully prepared surfaces of several well-annealed specimens of brass and steel by the conventional two-exposure normal and inclined incidence method. In the 58–42 brass, the alpha constituent showed a stress of -5270 lb/in.^{2}, the beta constituent $+6530$ lb/in.^{2}. Stresses on the ferrite constituent of the 1.05% carbon steel in the pearlitic, spheroidized, and decarburized conditions were found to be $+12\,740$, $+6050$, and $+4580$ lb/in.^{2}, respectively. These values were in reasonable agreement with values calculated by means of Laszlo's formulas.

[1] F. Laszlo, J. Iron Steel Inst. **147**, 173 (1943).

FRIDAY MORNING AT 9:30

Shoreham, West Ballroom

(T. H. BERLIN presiding)

Theoretical Physics III: Statistical Problems

LA1. Equivalent Statement of the Second Law. JOHN S. THOMSEN, *Johns Hopkins University.*—The second law of thermodynamics is most commonly given in the Kelvin-Planck or Claussius form and sometimes in the more abstract Carathéodory statement. A still different, but equivalent formulation may be given in two parts as follows: (1) Consider

a system having a single mechanical degree of freedom with force X, displacement x, energy u, and temperature t measured on an (almost) arbitrary scale. The quantity

$$\int_{t_0}^{t'}\left\{\left(\frac{\partial X}{\partial t'}\right)_x \Big/ \left[X+\left(\frac{\partial u}{\partial x}\right)_t\right]\right\}^2 dt',$$

is a function of temperature alone and is the same function for all such systems. (Generalization to other systems is straightforward.) This statement gives a directly verifiable equality involving only equilibrium quantities; it makes no reference to engines, cycles, quasistatic processes, or absolute temperatures. Absolute temperature, entropy, and all results of reversible thermodynamics follow as consequences. The second portion of the law is: (2) $\dot{S}\geq 0$ for an isolated system.

LA2. New Foundation of Macroscopic Thermodynamics for Matter, Antimatter, and Space Alike. AUSTIN J. O'LEARY, *The City College of New York.*—The new thermodynamics resembles that of Carathéodory and Born in the use of an integrating factor, but is otherwise fundamentally different in that conservation of energy is the sole condition for integrability in this final form, that there exists no state in which T is quite equal to zero—new form of the so-called third law. It will be shown that the theory permits existence of systems on both sides of absolute zero with m, P, T, and U either all positive or all negative. Presentation of results will be limited mainly to internally stable systems with negative m, P, T, and U. (1) They are sinks for radiation, do not radiate at all themselves, and hence must be almost completely degenerate by now but can never be completely degenerate since T can never quite be zero. (2) Taking space to be composed of them, a vacated negative energy state or hole in space is antimatter. (3) Space can still absorb radiation in infinitesimal amounts, $T\neq 0$, from which we infer that photons from distant galaxies can acquire red shifts in proportion to the length of path, the universe not expanding.

LA3. Linearized Boundary Problems in Kinetic Theory.* S. ZIERING, *Syracuse University,* AND E. P. GROSS, *Brandeis University.*—The steady flow of a gas between two parallel plates is investigated by solving the linearized Boltzmann equation with the distribution function subject to simple microscopic boundary conditions. Examination of the low-pressure limit shows the essentially discontinuous nature of the distribution in velocity. To satisfy boundary conditions, one should distinguish between velocities directed towards and away from a solid. Accordingly we follow Yvon's method in radiative transfer theory, and expand each section of the distribution in polynomials orthogonal over the respective half of the velocity range. The space dependent coefficients satisfy a set of linear differential equations. This technique is applied to the problems of shear flow and heat conduction to obtain solutions valid for arbitrary ratios of mean free path to plate separation. Linearization restricts the validity to low speeds and small temperature differences. Numerical results are obtained for inverse fifth and hard sphere molecules. Rapid convergence over the entire pressure region is a direct consequence of strict embodiment of the discontinuous feature. The lowest approximation agrees with high approximations of the slowly convergent full range methods of Chang and Uhlenbeck and Mott-Smith.

* Research supported by Office of Scientific Research.

LA4. Stochastic Analysis of a Variable Subject to a Quantum Force Spectrum. HANNA GOLDRING AND ARMAND SIEGEL, *Boston University.*—We have solved the problem of the diffusion of a variable f subject to the Langevin-type equation $\dot{f}+\gamma f=a(t)$, where the random force $a(t)$ has the spectral density $\hbar\omega/[\exp(\hbar\omega/kT)-1]$, i.e., Nyquist's quantum form of the noise spectrum.[1] Assuming Gaussian distribution for $a(t)$, we get the conditional probability $P[f(t)|f(t_0)]$ by calculating the correlation function[2] of f: $\langle f(t_0)f(t_0+t)\rangle/\langle f(t_0)^2\rangle$. Verification of the validity of the assumed spectrum could in principle be obtained with these results through direct analysis of noise curves in time. (Work is now in progress toward a similar analysis of diffusion of colloidal particles.) The extremely slow fall-off with frequency of the quantum noise spectrum, even at quite low temperatures, still presents an obstacle to experimental verification, in that extremely fine time resolution of the measured curves would be required.

[1] H. Nyquist, Phys. Rev. **32**, 110 (1928); H. B. Callen and T. A. Welton, Phys. Rev. **83**, 34 (1951).
[2] Ming Chen Wang and G. E. Uhlenbeck, Revs. Modern Phys. **17**, 323 (1945).

LA5. Correlation Times of Fluxes in the Quantum Theory of Transport Processes.* HAZIME MORI, *Brown University.*—The various kinetic coefficients can be expressed in terms of the correlation function of the corresponding flux F, $\Psi(t)=\langle FF(t)+F(t)F\rangle$. We mainly consider the viscosity coefficient of the quantum gases η, where $F=\sum_{i=1}^{N} p_{ix}p_{iy}$. The change with time of the Heisenberg operator $F(t)$ can be described by an operator $T(t,t_0)=\exp[(t-t_0)L]$, where $LF=[F,H]/i\hbar$. In order to separate the effects due to the molecular interaction from the free motion, define $K(t,t_0)=\exp(-tL_0)T(t,t_0)\times\exp(t_0L_0)$, where L_0 is the L operator of the kinetic energy H_0. Then, the binary collision approximation leads, in the limit of $N\to\infty$, to $K(t,0)=\exp[\sum\sum_{i<j} w_{ij}(t)]$, where w_{ij} is related to the scattering matrix for the collision between molecules i and j to give $\langle p|w_{ij}F|p\rangle=\hbar\Omega_{ij}\langle p|F|p\rangle$. Ω_{ij} is the collision integral operator familiar in the kinetic theory of dilute gases and contains the complete quantum-mechanical scattering cross section. $\psi_{ij}=p_xp_y$, $(p=p_i-p_j)$, is an eigenfunction of Ω_{ij} with the eigenvalue $\omega_{ij}=-3|p|Q(p)/mv$, where $Q(p)$ is the transport cross section. Thus, if, on the average, the deviation of the ω_{ij} is small from their average value as for the classical Maxwell molecule, then the correlation function decays exponentially with time to give $\eta=4\langle F^2\rangle/3nkT\langle 2|p|\times Q/m\rangle$. The behavior of η will be discussed for some potential functions.

* Supported in part by the U. S. Air Force.

LA6. Grand Partition Function for Polyphase Systems Involving Long-Range Forces. W. G. MCMILLAN, *University of California, Los Angeles, and The RAND Corporation.*—Motivated by the remarkable absence in the literature of a partition function for the Thomas-Fermi (TF) atom at arbitrary temperature, a general method has been developed for the statistical treatment by the method of the grand partition function Ξ of a system of (possibly degenerate) particles interacting with long range (e.g., Coulomb) forces in the presence of an external field. Under such conditions it is no longer possible to hold constant all intensive properties during assembly of the system, so that $\Xi(=\sum\lambda^N\sum\exp-\beta E_k)$, now has to be identified thermodynamically with $\exp\beta\sum(p^\alpha V^\alpha-\int V^\alpha dp^\alpha)$, where α designates a "phase" throughout which the pressure is uniform, and the integral relates to the reversible isothermal process of assembly. By neglecting quantities of second order n the density fluctuation, Ξ may be cast in the form appropriate to strongly interacting particles moving in a self-consistent potential. Elementary operations then lead to the other thermodynamic functions and to the virial theorem which, for the TF atom, correctly reduce to the results of Brachman.[1] However, his conclusion that the Gibbs free energy is not extensive in the number of electrons is shown to be a consequence of treating the nucleus as an external field, rather than as one of the components of the mixture.

[1] M. K. Brachman, Phys. Rev. **84**, 1263 (1951); J. Chem. Phys. **22**, 1152 (1954).

LA7. Application of Macke's Statistical Density to the H.O.* M. G. KIVELSON, *The RAND Corporation.*—The problem of the linear harmonic oscillator with the first ten levels singly occupied has previously been studied as a convenient test of the accuracy of various statistical procedures for the calculation of the particle density function. Of the three procedures studied,[1] only the Plaskett[2] modification of the Thomas-Fermi method was found capable of reproducing the fluctuations of the exact wave mechanical density, $\rho(x)$. The form of the Plaskett density, however, depends critically on the choice of an arbitrary parameter. A calculation of the particle density ($\rho_M(x)$) has been carried out using the approximate wave mechanical procedure proposed by Macke.[3] $\rho_M(x)$ is found to fluctuate with a wavelength which is close to the wavelength of $\rho(x)$, although the amplitude of fluctuation is somewhat too large. $\rho_M(x)$ reproduces the general form of $\rho(x)$ almost as well as does the Plaskett density with the parameter selected for best fit, and, furthermore, is specified uniquely.

* This study was performed by the author as a Consultant to the RAND Corporation and was sponsored by the U. S. Atomic Energy Commission.
[1] R. A. Ballinger and N. H. March, Proc. Phys. Soc. (London) **A67**, 378 (1954).
[2] J. S. Plaskett, Proc. Phys. Soc. (London) **A66**, 178 (1953).
[3] W. Macke, Phys. Rev. **100**, 992 (1955).

LA8. Collective Modes of Oscillation for the Many-Body Problem at High Density.* J. K. PERCUS AND G. J. YEVICK, *Stevens Institute of Technology.*—We are seeking the normal modes of oscillation for the many-body problem. As an aid to analysis, we first determine the normal coordinates at the two extremes of density (relative to range of force). Our hope is to bridge the gap between the low- and high-density regions. Since the direct high-density or strong coupling limit is a static one, a preliminary scale transformation in time and space is required. If the interaction potential is expanded about equilibrium position, and terms through quadratic are retained for the zeroth approximation, diagonalization of the Hamiltonian is straightforward, yielding normal coordinates which may be identified with the $q_k = \Sigma \exp ikx_l$ previously considered. Further, the frequencies are given as finite-difference Fourier coefficients of the potential. Introducing the higher order potential terms as perturbation, and solving directly for the normal coordinates, a standard linear operator perturbation problem results. The new normal coordinates are collective variables which as expected involve both coordinates and momenta in a fairly complicated manner, where as there is no first-order frequency shift. Techniques for analyzing these novel coordinates, and extension to short-range forces, will be presented.

* Supported by the Office of Naval Research.

LA9. Normal Modes of Oscillation for the Many-Body Problem at Low Density.* G. J. YEVICK AND J. K. PERCUS, *Stevens Institute of Technology.*—The analysis for the normal modes of oscillation at low density is distinct from that at high density in that there now exists a dynamical limit, namely the free particle limit. The new difficulty, that the limit is characterized by individual rather than by collective behavior, is overcome by exhibiting a class of transformations which enables one to pass freely from individual to collective picture. Next we switch on the interaction potential and determine the angle-action variables by a perturbation technique. This necessitates the solution of a set of first-order partial differential equations subject to the "boundary conditions" that the new angle-action variables remain canonically conjugate. From these angle-action variables, which are made collective by the transformations discussed above, the normal coordinates are readily obtained. The character of these normal coordinates appears most unusual: typical terms which occur are of the form of the ratio of relative potential to relative momentum. The nature of the connection between the new collective coordinates and those obtained from the high density limit appears at first sight a highly tenuous one. Attempts at bridging the gap will be presented.

* Supported by the Office of Naval Research.

FRIDAY MORNING AT 9:30

Shoreham, Main Ballroom

(C. S. WU presiding)

Experimental Papers with a Bearing on Parity

M1. Depolarization of Positive Muons in Matter.* D. BERLEY, T. COFFIN, R. GARWIN, L. LEDERMAN, AND M. WEINRICH, *Columbia University.*—We have investigated the state of polarization of muons after stopping in various materials. Preliminary evidence shows that the muon beams are nearly 100% polarized. This is deduced by comparing the asymmetries obtained in the muon beam[1] with those observed by $\pi-\mu-e$ decay in nuclear emulsion,[2] in propane bubble chambers[3] and in liquid hydrogen bubble chambers.[4] The depolarization in various materials is studied by measuring the peak to valley ratios with a standard requirement of 9.3 g/cm^2 on the decay electron energy. The results are for μ^+ mesons: C; 1.80 ± 0.08; CH_2, 1.60 ± 0.15; emulsion, 1.38 ± 0.09; calcium, 1.66 ± 0.10; aluminum, 2.00 ± 0.20; H_2O, 1.41 ± 0.10; sulfur, 1.0 ± 0.08; NaCl, 1.0 ± 0.15. In the case of nuclear emulsions, the depolarization was unchanged when the precession time was decreased, thus decreasing the average time which the muon spends in equilibrium before decay. These results will be discussed.

* Supported by the Office of Naval Research and the U. S. Atomic Energy Commission.
[1] Garwin, Lederman, and Weinrich (to be published).
[2] J. Friedman and V. Telegdi (to be published).
[3] I. Pless and R. Williams (private communication).
[4] R. Adair *et al.* (to be published).

M2. Energy Dependence of the Asymmetry in Polarized Muon Decay.* T. COFFIN, R. GARWIN, L. LEDERMAN, M. WEINRICH, AND D. BERLEY, *Columbia University.*—In a continuation of recent experiments, we are studying the energy dependence of the asymmetry of the positron angular distribution arising from decay of polarized muons. This is done by determining the ratio of the maximum to the minimum positron rate in the angular distribution as a function of thickness of carbon traversed by the positrons. The following results are at hand: For carbon thicknesses of 9.3, 15.6, 19.2,

22.2, 24.5, and 25.8 g/cm² we find peak-to-valley ratios of 1.80 ± 0.08, 1.84 ± 0.1, 2.14 ± 0.10, 2.24 ± 0.35, 3.17 ± 0.64 and 4.55 ± 1.6, respectively. When resolution effects are included, the distribution corresponding to the 9.3 g/cm² point is found to be $f(\theta)=1-0.305\pm0.033\cos\theta$ for positive muons in carbon. If this point is used to normalize the theoretical expressions given by Lee and Yang, then the data may be compared with the predictions of the two-component theory. To do this, the positron range calibration curves provided us by the Chicago betatron group are used. The tentative results indicate good agreement with the choice $\mu^+\to e^++\nu+\bar{\nu}$.

* Supported by the Office of Naval Research and the U. S. Atomic Energy Commission joint program.

M3. Remarks on Formation of Muonium in Gases.* VERNON W. HUGHES, *Yale University and Columbia University.*—The existence of polarized μ^+ mesons from the π^+ decay and the angular asymmetry in the distribution of e^+ decays from μ^+, which are associated with parity nonconservation, may make possible studies of the hyperfine structure (hfs $\simeq$4500 Mc/sec) of the bound state of a μ^+ meson and an electron (muonium). With this motivation estimates have been made of cross sections relevant to the formation of muonium in gases. At kinetic energies of order $(e^2/a_0)(m_\mu/m_e)$, for which the μ^+ meson's velocity is comparable to the velocities of electrons in a gas molecule, the cross section for the capture of an electron by a μ^+ meson is of order πa_0^2; the cross section for the ionization of muonium is of similar magnitude. At sufficiently low kinetic energies so that the breakup of muonium is energetically forbidden the cross section is several orders of magnitude smaller. For a gas with an ionization energy less than the binding energy of muonium (13.5 ev) muonium formation competes with decay of the free μ^+ meson and with attachment of μ^+ to a gas molecule. For a gas with ionization energy greater than 13.5 ev the μ^+ meson may fall below the threshold for muonium formation due to inelastic and elastic collisions and will then decay without forming muonium.

* Research supported in part by A. F. Office of Scientific Research and by U. S. Atomic Energy Commission.

M4. Experiments on Parity Nonconservation. I. Decay Asymmetry of the Free μ^+.* R. A. SWANSON, N. P. CAMPBELL, E. L. GARWIN, J. C. SENS, V. L. TELEGDI, S. C. WRIGHT, AND D. D. YOVANOVITCH, *University of Chicago.*—The violation of parity (and charge conjugation) conservation in the $\pi^+\to\mu^+\to e^+$ decay chain has recently been established experimentally.[1,2] An asymmetry of the form $W(x)=1+ax(x=\hat{p}_e\cdot\hat{p}_\mu)$ has been observed here in the decay of polarized μ^+'s in precession experiments similar to those of reference 1. The μ^+ contamination of a 62-Mev "π^+" beam was stopped in various materials placed in a field of 88 gauss. The decay e^+ were detected with a 2-counter telescope placed at 90° to the incident beam, defined by a similar telescope. Delays between beam and e^+ pulses were converted to pulse heights by means of a conventional circuit[3] modified to cover 2.7 μsec, and the delay spectra were displayed on a 100-channel analyzer. Thus $x=\cos\omega(\omega=g\mu_0B/207)$, and after correction for decay a is obtained directly. We find for $-a$: graphite, 0.27 ± 0.02; Be, 0.22 ± 0.02; Teflon, 0.19 ± 0.03; SiO_2(cryst), <0.05; SiO_2(fused) <0.05; propane (liquid), 0.18 ± 0.015.

* Research supported by joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.
[1] Garwin, Lederman, and Weinrich, Phys. Rev. (to be published).
[2] J. I. Friedman and V. L. Telegdi, Phys. Rev. (to be published).
[3] Weber, Johnstone, and Cranberg, Rev. Sci. Instr. **27**, 166 (1956).

M5. Experiments on Parity Nonconservation. II. Search for "Muonium" (μ^+e^-).* N. P. CAMPBELL, E. L. GARWIN, J. C. SENS, R. A. SWANSON, V. L. TELEGDI, S. C. WRIGHT, AND D. D. YOVANOVITCH, *University of Chciago.*—The formation of a (μ^+e^-) atom, "muonium" can be the possible cause for the reduced asymmetry of $\mu-e$ decay in certain materials. From completely polarized, $s=\frac{1}{2}\mu^+$'s 50% of these atoms would be formed in a $^3S_1$, $m=|1|$ state, while the other 50% would depolarize itself rapidly owing to hf splitting and could anyhow not contribute to precession effects being in an $m=0$ state. Conversely, if the state with $m=|1|$ is formed, and not depolarized within about a microsecond, it should precess in weak external fields and yield the same effects as the free μ^+ in high fields. Precession experiments would give the g factor and hence a *direct* clue to the spin of the muon.—By analogy with positronium experiments in solids, it was anticipated that muonium would be formed in Teflon and fused SiO_2 (Vitreosil) in appreciable amounts. These substances indeed exhibit less asymmetry than metals, but the fused SiO_2-cryst·SiO_2 difference observed in positronium experiments does not arise. We performed precession experiments in Teflon and Vitreosil at 0.4 gauss; no conclusive evidence for muonium precession has been obtained to date. Experiments with these and other materials are being continued, and their results will be reported.

* Research supported by joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.

M6. Experiments on Parity Nonconservation. III. Energy Dependence of Asymmetry.* E. L. GARWIN, N. P. CAMPBELL, J. C. SENS, R. A. SWANSON, V. L. TELEGDI, S. C. WRIGHT, AND D. D. YOVANOVITCH, *University of Chicago.*—The coefficient a governing the asymmetry of electron emission in the decay of polarized muons will in general be a function of the electron energy, and conversely the decay spectrum will depend on the direction of observation with respect to the muon spin axis. The functional dependence is governed by the type of decay interaction assumed; the recently advanced two-component theory of the neutrino[1] in particular makes rather specific predictions for $a(p_e)$. In the apparatus described in a preceding abstract,[2] the 2-counter electron telescope has been replaced by a plastic scintillator and a NaI(Tl) crystal (5 in. diam, 4 in. long) to obtain good energy resolution. The NaI spectrometer was calibrated with electrons up to 50 Mev from the Chicago betatron. Measurements are in progress, and their results will be compared both with theoretical predictions and experiments in which varying thicknesses of absorber are used for energy discrimination.[3]

* Research supported by joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.
[1] Abdus Salam (unpublished); Lee and Yang (unpublished); L. D. Landau, preprint obtained from the Institute for Advanced Study.
[2] Swanson, Campbell, Garwin, Sens, Telegedi, Wright, and Yovanovitch, Bull. Am. Phys. Soc. Ser. II, **2**, 205 (1957), this issue.
[3] Garwin, Lederman, and Weinrich, Post-deadline paper at the 1957 New York Meeting, and subsequent private communication.

M7. Angular Distribution of Low-Energy Positrons from μ^+-e^+ Decays.* I. A. PLESS, A. E. BRENNER, AND R. W. WILLIAMS, *MIT*, R. BIZZARRI AND R. H. HILDEBRAND, *University of Chicago*, AND R. H. MILBURN, N. F. RAMSEY, A. M. SHAPIRO, K. STRAUCH, J. C. STREET, AND L. A. YOUNG, *Harvard University.*—A 6-in. diam propane bubble chamber has been exposed in the 82 Mev π^+ beam of the University of Chicago Synchrocyclotron. A magnetic shield reduced the remanent magnetic field in the chamber to less than 0.2 gauss. An analysis is being made of the $\pi^+-\mu^+-e^+$ events occurring in the chamber. On the average five such events are seen on each photograph. All events in which the decay electron stops in the chamber (energy less than 12 Mev) are being analyzed for the space angle between the μ^+ and e^+ directions. To date, 117 such have been measured and the results are 0°–60°:31; 60°–90°:29; 90°–120°:30; 120°–180°:27. These data suggest a reduction of the backward excess observed when high-energy electrons predominate.[1] Such a reduction has been predicted by Lee and Yang.[2] Further results will be reported.

* This work has been supported in part by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.
[1] Garwin, Lederman, and Weinrich (to be published); V. L. Telegdi and J. Friedman (to be published).
[2] T. D. Lee and C. N. Yang (to be published).

M8. Spin Momentum Correlation in the Beta Decay of Polarized Li^8 Nuclei.* M. T. BURGY, W. C. DAVIDON, T. B. NOVEY, G. J. PERLOW, AND R. RINGO, *Argonne National Laboratory.*—Observations have been made which corroborate the experiments of Wu,[1] Garwin *et al.*,[2] and Telegdi[3] on the failure of the beta-decay interaction to satisfy the previously assumed requirement of parity conservation. These effects have been observed in the beta decay of polarized Li^8 nuclei produced by the capture of polarized thermal neutrons by Li^7 in Li_2CO_3. These neutrons were obtained using the Argonne CP-5 reactor and were polarized by the transmission method. Preliminary data give an anisotropy $(n_+-n_-)/(n_++n_-) = -0.04\pm0.01$ in a beam that was 26% polarized where n_+ and n_- are, respectively, the numbers of electrons emitted in and opposite to the direction of the neutron spin. The usual spin-spin coupling, which would depolarize the Li^8 nucleus, is reduced by the fact that the g factor for the Li^8 is different from that for the surrounding Li^7 nuclei. The effect of the formation of F centers in reducing the relaxation time and reducing the anisotropy has been observed. Thermal annealing of the sample restores the anisotropy.

* Based on work performed under the auspices of the U. S. Atomic Energy Commission.
[1] C. S. Wu *et al.*, Phys. Rev. (to be published).
[2] Garwin, Lederman, and Weinrich, Phys. Rev. (to be published).
[3] J. I. Friedman and V. Telegdi, Phys. Rev. (to be published).

M9. Interpretation of the Anisotropy Observed in the Beta Decay of Polarized Li^8.* D. KURATH, *Argonne National Laboratory.*—The polarization of Li^8 nuclei formed in the capture of polarized thermal neutrons by Li^7 is determined by the J of the capturing channel. Since the Li^7 ground state is $I=\frac{3}{2}^-$, capture of s neutrons will lead to $J=1^-$ or 2^-, which then decays by electric dipole emission to the Li^8 ground state, $I=2^+$. The polarization of the Li^8 ground state as measured by the expectation value of I_z is

$$\langle I_z\rangle = -\tfrac{1}{3}P \quad \text{for } J=1^-$$
$$\langle I_z\rangle = +\tfrac{2}{3}P \quad \text{for } J=2^-,$$

where P is the fractional polarization of the incident neutrons. The sign and degree of anisotropy observed in the beta decay give information indicating a preferred channel for formation of Li^8. The results of this comparison will be presented.

* Based on work performed under the auspices of the U. S. Atomic Energy Commission.

M10. Angular Distribution of the Electrons in Cosmic-Ray $\pi\cdot\mu\cdot e$ Decays. C. M. G. LATTES, P. F. FOWLER, P. FREIER, E. P. NEY, AND S. J. ST. LORANT, *University of Minnesota.*—The angular distribution of the decay electrons from cosmic-ray μ mesons has been measured with respect to the direction of ejection of the μ in the π decay at rest. The meson decays were observed in a 20-liter stack exposed for 8 hr at a residual pressure of 6 g/cm². The only external magnetic field present was that of the earth. With accelerator produced mesons stopping in emulsion, the angular distribution has been found to have a backwards peak.[1] If the angular distribution is of the form $1-a\cos\theta$, our data based on 700 particles indicate an $a=0.0\pm0.07$ in contrast to $a=0.18\pm0.03$ for the accelerator experiments. The foregoing experiment was started after the results of the Columbia[2] and Chicago group were made known.

[1] J. Friedman and V. Telegdi (private communication).
[2] Garwin, Lederman, and Weinrich (private communication).

FRIDAY MORNING AT 9:30

Sheraton Hall

(H. D. SMYTH presiding)

Invited Papers

MA1. Radioactive Fallout. W. F. LIBBY, *Atomic Energy Commission.* (40 min.)

MA2. On the Energy Spectra of Nuclei. AAGE BOHR, *University of Copenhagen.* (40 min.)

MA3. Catalysis of Nuclear Reactions by Mu Mesons. HUGH BRADNER, *University of California, Berkeley.* (40 min.)

FRIDAY AFTERNOON AT 1:15

Sheraton Hall

(F. J. DYSON presiding)

Symposium on the Nonconservation of Parity

N1. Conservation Laws in Weak Interactions. T. D. LEE, *Columbia University.* (30 min.)

N2. Nonconservation of Parity and of Charge Conjugation in Beta Decay. C. S. WU, *Columbia University.* (30 min.)

N3. Columbia Experiments on Polarized Muons. R. L. GARWIN, *IBM Watson Laboratory.* (30 min.)

N4. Work of the Chicago Group on Nonconservation of Parity. V. L. TELEGDI, *University of Chicago.* (30 min.)

N5. Beta Spectrum from the Decay of Positive Muons. K. L. CROWE, *Stanford University.* (30 min.)

FRIDAY AFTERNOON AT 2:00

Sheraton-Park, Continental Room

(H. W. LEWIS presiding)

Coulomb Excitation; Interactions Involving Deuterons and Alpha Particles

P1. Coulomb Excitation of States in $_{90}Th^{232}$. F. K. MCGOWAN AND P. H. STELSON, *Oak Ridge National Laboratory.*—Gamma rays of 790-, 740-, and 613-kev energy are observed when Th^{232} is bombarded with 4.0 to 6.0 Mev protons. The angular distribution of each gamma ray with respect to the incident proton beam has been measured at $E_p = 5.0$ Mev. Both the variation in gamma-ray yields with proton energy and the results from the angular distribution measurements are consistent with the direct excitation of a 2+ state at 790 kev which decays by means of $E2$ radiation to the $I = 0+, 2+$, and possibly the 4+ members of the ground-state band. The reduced transition probabilities for $E2$ decay, $B(E2)_d$, are (4.36 ± 0.50), (8.2 ± 1.2), and $(7.2 \pm 1.1) \times 10^{-50}$ e^2 cm^4. These $B(E2)_d$ are larger than those given by the independent particle estimates by factors of 5, 10, and 8.5. The 50-kev gamma ray resulting from Coulomb excitation of the 2+ state of the ground-state rotational band has been observed when Th^{232} is bombarded with 3.0 to 4.0 Mev α particles. Taking $\alpha_T = 333$, we obtain $B(E2)_d = (1.33 \pm 0.20) \times 10^{-48}$ e^2 cm^4 for this transition which is 157 times the independent particle estimate.

P2. Coulomb Excitation of Cs and Ba. L. W. FAGG, *Naval Research Laboratory.*—Studies have been made of the gamma-ray spectra of Cs and isotopically enriched Ba^{136} and Ba^{137} when bombarded by three-to-five Mev alpha particles from the Naval Research Laboratory large Van de Graaff generator. The spectra were examined with a 2-in. NaI spectrometer whose energy and efficiency were calibrated with standard sources. The following gamma rays were observed: Cs, 82, 160, 302, and 379 kev[1]; Ba^{135}, 214 kev; Ba^{137}, 281 kev. The thick target excitation curve for the 302-kev gamma ray matches the theoretically calculated curve for a level at 379 kev. This implies that the level at 379 kev decays by cascade through the 82-kev level in agreement with studies of the Ba^{132} β decay.[2] Measurements of the reduced transition probabilities for excitation will be presented. The results of investigations of some of the even Ba isotopes will also be discussed.

[1] G. M. Temmer and N. P. Heydenburg report an 85-kev gamma ray from Cs, Phys. Rev. **93**, 351 (1954).
[2] M. Langevin, Compt. rend. **240**, 289 (1955).

P3. Counter System for Identifying Mass and Measuring Energy of Charged Particles.* KEITH BOYER, J. A. NORTHROP, AND R. H. STOKES, *Los Alamos Scientific Laboratory.*—The study of the proton energy spectrum in coincidence with fission induced by the (d,p) stripping reaction on fissionable nuclides required a high solid angle counter system capable of discriminating against other charged particles in the same energy range. The system developed identifies the particle by solving the relation $\text{Mass} = kz^2(E + E_0)\Delta E/\Delta x$ and accepting only those particles with a specified mass. The rate of energy loss, $\Delta E/\Delta x$, is measured by a transmission ion chamber, the energy, E, is measured by a sodium iodide scintillator, and the multiplication is performed by adding the logarithms of the pulse heights. The discrimination obtained is limited by the energy loss straggling in the ion chamber and by inaccuracies in the multiplier. For a loss of 1.2 Mev, deuteron pulses out of the ion chamber have a width of 11% and a discrimination of 10^2 is obtained between deuterons and protons.

* Work performed under the auspices of the U. S. Atomic Energy Commission.

P4. Coincidence Techniques for Cyclotron Experiments.* J. A. NORTHROP, R. H. STOKES, AND KEITH BOYER, *Los Alamos Scientific Laboratory.*—In order to obtain fission thresholds using the (d,p) stripping reaction to induce fission, it was necessary to minimize and accurately measure the chance background when taking coincidences between protons and fission events. In addition to the natural bunching at the rf rate, an external cyclotron beam is generally modulated strongly at frequencies extending to several hundred kilocycles and thus it is necessary to measure the chance rate by a delayed coincidence technique. In the system used for these experiments, the resolving time was less than the interval between natural bunches. The true-plus-chance channel recorded coincidences between protons and fission events belonging to the same bunch and the chance channel recorded coincidences between fission events from one bunch and protons from two bunches later. Two pulse-height analyzers were used to record simultaneously the proton energy spectrum associated with each channel. Care was taken to treat both channels identically to make their chance sensitivity equal at every energy.

* Work performed under the auspices of the U. S. Atomic Energy Commission.

P5. Fission Thresholds from (d,p) Stripping Reactions.* R. H. STOKES, KEITH BOYER, AND J. A. NORTHROP, *Los Alamos Scientific Laboratory.*—Fission thresholds have been determined for U^{235} and U^{238} by measuring the energy spectrum of protons in coincidence with fission events induced by 14-Mev deuterons. The rise in the $U^{238}(d,p\text{-}f)$ cross section as a function of excitation energy of the fissioning nucleus is in fair agreement with data from neutron-induced fission. Using a published value for the neutron binding energy, the excitation energy to produce fission in U^{238} is about 5 Mev corresponding to a neutron fission threshold in U^{238} of -1.5 Mev. A peak with a width of $\frac{1}{2}$ Mev is superimposed on the $U^{238}(d,p\text{-}f)$ cross-section curve at an excitation energy corresponding to the addition of a thermal neutron. Further comparisons between these data and those obtained from neutron-induced fission will be presented.

* Work performed under the auspices of the U. S. Atomic Energy Commission.

P6. Interaction of 6-Mev Deuterons with Tritium and He^3.* J. E. BROLLEY, JR., W. S. HALL, AND L. ROSEN, *Los Alamos Scientific Laboratory.*—Six-Mev cyclotron accelerated deuterons were used as the bombarding particles in a nuclear multiplate camera. Angular distributions for scattering and for reactions were obtained with T or He^3 as targets. The elastic scattering from both targets is quite similar and is characterized by a secondary maximum near 90° c.m. The He^3 scattering cross section is depressed below the tritium scattering in this region. Similarly, the two primary reactions $D + T \rightarrow n + He^4 + 17.6$ Mev and $D + He^3 \rightarrow p + He^4 + 18.4$ Mev have almost identical angular distributions in this region with an incipient maximum in the vicinity of 70° c.m. As in the $D+D$ primary reactions, neutron production is slightly more prolific than proton production. In the $D+T$ reaction our charged particle measurements are in good accord with neutron measurements.[1]

* This work performed under the auspices of the U. S. Atomic Energy Commission.
[1] S. J. Bame, Jr. (private communication); A. Galonsky and C. H. Johnson, Phys. Rev. **104**, 421 (1956).

P7. $T(d,2n)He^3$ Reaction.* L. Rosen, J. E. Brolley, Jr., and W. S. Hall, *Los Alamos Scientific Laboratory.*—In addition to the reactions $T(d,n)He^4$ and $T(d,pn)T$, we have recently identified the previously unobserved subject reaction at 12- and 14-Mev deuteron energies. The He^3 particles were detected in nuclear emulsions and identified as doubly charged particles on the basis of their specific ionization. These particles are attributed to the $T(d,2n)He^3$ reaction rather than to an excited state of He^4 on the basis of energy and momentum considerations. The end points of the range distributions at the various angles correspond accurately to the maximum energies available to the He^3 particles. The range distributions show no evidence for a bound state of the di-neutron, nor for a virtual level of width less than 0.5 Mev. However the inferred He^3 energy distributions do not agree well with that calculated for a three-body process occurring with random probability in momentum space. The deviations, although not startling, appear to be significant and may be a consequence of interaction between the outgoing neutrons. It is anticipated that the analog reaction $He^3(d,2p)T$ will proceed with approximately the same probability as the subject reaction, the cross section for which appears to exceed the $He^3(d,p)He^4$ cross section at these energies.

* Work performed under the auspices of the U. S. Atomic Energy Commission.

P8. Angular Distributions of Protons from $B^{10}(d,p)B^{11}$ Reactions.*† K. S. Lee and N. S. Wall, *MIT.*—The angular distributions of the two highest groups of protons from $B^{10}(d,p)B^{11}$ reactions were studied with the 15.1-Mev deuteron beam obtained from the MIT cyclotron. A NaI(Tl) scintillation spectrometer, with a Lucite absorber, was used to detect the protons. This absorber eliminated the elastically scattered deuterons and increased the relative energy separation of the two proton groups we studied. The target used was $B_2{}^{10}O_3$. The results of the measurements were in agreement with the theory of stripping for both groups. The result for ground state, $l_n=1$, was consistent with those obtained elsewhere.[1,2] However, the present result showing stripping for the first excited state gave an l_n value of $l_n=2$. Neither a direct stripping reaction or any (d,p) reaction interpretable as having an $l_n=2$ component has been observed to date with deuteron energies up to 10 Mev.[3] The significance of these results will be discussed.

* Thesis submitted by one of us (K.L.) at Massachusetts Institute of Technology.
† This work was supported in part by a joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.
[1] N. T. S. Evans and W. C. Parkinson, Proc. Phys. Soc. (London) **A67**, 684 (1954).
[2] J. R. Holt and T. N. Marsham, Proc. Phys. Soc. (London) **A66**, 1032 (1953).
[3] B. Zeidman and J. M. Fowler, Bull. Am. Phys. Soc. Ser. I, **1**, 325 (1956).

P9. Excitation Curves for the $Ca^{40}(d,p)Ca^{41}$ Reaction.* L. L. Lee, Jr., and J. P. Schiffer, *Argonne National Laboratory.*—Excitation functions for the $Ca^{40}(d,p)Ca^{41}$ (ground-state) reaction have been studied with a 30-kev thick Ca target at 30°, 90°, and 150° from 1.50 to 4.22 Mev bombarding energy. The total cross section ranges from 0.1 to 10 mb over the energy range studied. At least 30 resonances in the excitation function were observed with widths approximately equal to or less than the target thickness. The intensity of the resonances indicates that compound nucleus formation accounts for at least 20% of the reaction. Angular distributions were measured at 7.5° intervals between 0° and 157.5° in the laboratory system. Although these show strong fluctuations over resonances a general forward peaking is apparent throughout the energy region studied.

* Work performed under the auspices of the U. S. Atomic Energy Commission.

P10. (p,d) Reactions in Light Nuclei.* Edgar F. Bennett, *Princeton University.*—The angular distributions of deuterons from reactions induced by 18 Mev protons have been measured using targets of Be^9, C^{13}, N^{15}, F^{19}, Mg^{25}, and P^{31}. A thin proportional counter velocity selector in conjunction with a NaI crystal for energy determination was found to be adequate for identifying deuteron groups unambiguously. Deuteron groups leading to the ground and one or more low-lying excited states of the residual nucleus were observed and the distribution in each case was fitted with a Butler[1] type curve. Reduced widths for neutron emission were extracted from the data, and compared with the shell model predictions for $C^{13}(p,d)C^{12}$, $N^{15}(p,d)N^{14}$, and $F^{19}(p,d)F^{18}$. Results of these calculations will be presented.

* This work was supported by the U. S. Atomic Energy Commission and the Higgins Scientific Trust Fund.
[1] S. T. Butler, Proc. Roy. Soc. (London) **A208**, 559 (1951).

P11. Differential Cross Sections for $Pb^{206}(d,p)Pb^{207}$ Reactions.* M. T. McEllistrem, H. J. Martin, D. W. Miller, and M. B. Sampson, *Indiana University.*—In an effort to investigate the effectiveness of stripping reactions as a spectroscopic tool in heavy nuclei, the $Pb^{206}(d,p)Pb^{207}$ proton groups to the ground and first seven excited states of Pb^{207} have been studied. Thin targets of 88% Pb^{206} ($\sim$0.25 mg/cm^2) were prepared by evaporation of radiogenic lead onto thin (0.004 mil) Au backings. The target thickness was determined from yield measurements of the elastic scattering of 21.8-Mev α particles at angles less than 60°. This scattering has been shown[1] to have the Coulomb angular dependence to within a few percent for such angles. The protons from the (d,p) reactions were observed with a double-focusing magnetic spectrometer. From proton energy measurements we find consecutive Q-value differences of 0.60, 0.35, 1.83, 0.92, 0.76, 0.27, and 0.57 Mev for the eight groups, beginning with the ground state-first excited state difference. All energies have uncertainties of $\pm$0.02 Mev. Differential cross sections for laboratory angles between 12.5° and 140° were measured at an incident deuteron energy of 10.8 Mev. Angular distributions show moderately pronounced maxima at angles near or less than 90°. Below the peak, the cross section varies rapidly with angle, but at large angles it drops slowly to 70–80% of the peak value.

* Supported by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.
[1] J. R. Rees, Ph.D. thesis, Indiana University, 1956 (unpublished).

P12. Elastic Scattering of Deuterons by Nuclei.* Warren Heckrotte and Henry P. Stapp, *University of California, Berkeley.*—The usual impulse approximation treatment of the elastic scattering of high-energy deuterons by nuclei takes into account the interaction of one or the other nucleons of the deuteron with the nucleus.[1] Such a treatment fails, however, to yield a satisfactory explanation of the experimental scattering cross section and polarization. The impulse approximation has been extended to include the effect of the simultaneous scattering of the two nucleons of the deuteron with the nucleus. This additional contribution is important at both large and small angles, and leads to a satisfactory fit of the differential cross section for 156-Mev deuterons incident on carbon.[1] The results of the calculation as they apply to the polarization of the deuteron will be reported.

* This work was done under the auspices of the U. S. Atomic Energy Commission.
[1] Baldwin, Chamberlain, Segrè, Tripp, Wiegand, and Ypsilantis, Phys. Rev. **103**, 1502 (1956).

P13. Angular Distributions of Alpha Particles and Deuterons Scattered by Heavy Nuclei.* John R. Rees† and M. B. Sampson, *Indiana University.*—The angular distributions of 22-Mev alpha particles and 11-Mev deuterons scattered elastically from uranium, bismuth, gold, and tantalum have been measured using the Indiana University cyclotron.

The same targets and apparatus were used for both deuteron and alpha-particle experiments so that a direct comparison of the differential cross sections for the scattering of the two particles from the same nucleus was obtained. The deuteron distributions invariably depart from Rutherford dependence ($\csc^4\theta/2$) at a smaller angle than do the alpha-particle distributions. The semiclassical theory of Ford and Wheeler which describes the potential scattering of charged particles at the nuclear surface accounts for the alpha-particle distributions strikingly well in the cases of gold and tantalum. In the cases of uranium and bismuth, theory and experiment are less compatible, and no agreement is obtained for deuteron scattering. The plausibility of the parameters used to obtain theoretical fits will be discussed.

* Supported by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.
† Now at Harvard University.

FRIDAY AFTERNOON AT 2:00

Sheraton-Park, Burgundy Room

(J. W. BEAMS presiding)

General Physics

Q1. Two-Cavity Maser Spectrometer.* A. JAVAN AND T. C. WANG, *Columbia University.*—A beam maser-spectrometer can be operated with two cavities. Microwave power is introduced into the first cavity and molecular emission is observed in the second cavity. The power emitted in the second cavity from a beam of uniform velocity distribution is

$$P = Nh\nu\left[\sin^2\left(\frac{|\mu_{12}|E_1\tau_1}{2\hbar}+\frac{|\mu_{12}|E_2\tau_2}{2\hbar}\right)-\sin^2\left(\frac{|\mu_{12}|E_1\tau_1}{2\hbar}\right)\right],$$

where N is the beam intensity, E_1 and E_2 the amplitudes of the electric field in the first and second cavity, τ_1 and τ_2 the transit times. In this equation it is assumed that the microwave frequency is at the resonance center. Hence, for small E_2, P is proportional to E_2. In contrast to this situation, in a one cavity system the emitted power is proportional to E^2 for small E. Now if the cavity loss is proportional to E^2, it can be shown that in the latter case, a threshold value for N is necessary to obtain a self-sustained oscillation. However, in a two cavity system, radiation is obtained in the second cavity for any value of N. The main ammonia $3-3$ line and its magnetic satellites are observed experimentally.

* Work supported jointly by the Signal Corps, the Office of Naval Research, and the Air Research and Development Command.

Q2. Sodium *D*-Line Atmospheric Emission Observation at High Altitudes. J. BLAMONT,* *University of Paris* (introduced by J. E. Mack).—It is not possible to observe sodium atmospheric emission from the ground with magnetic scanning apparatus[1] for a solar depression angle θ less than 1° because of the low-altitude scattering of sunlight. We have attempted to observe the emission during the day with the same technique at an altitude of 13 km. Four flights were performed during October, 1956 at this altitude in an airplane. The emission could not be observed during the day, but the absorption line observed during the day changed into an emission line near $\theta=0°$. The curve from the observation aloft is therefore essentially similar to that obtained on the ground. The intensity of the plateau is the same, while the time when the absorption changes to emission is shifted toward the day by not more than five minutes. The scattering observed in the high-altitude experiment is reduced before sunset, but not as much as expected. In order to observe possible emission during the day, experiments at higher altitudes are necessary.

* Now at the University of Wisconsin.
[1] J. Blamont, Compt. rend. **237**, 1320; J. Blamont, *Proceedings of the 1955 Belfast Symposium.*

Q3. Spectrum of Turbulent Fluctuations Produced by Convective Mixing of Gradients. ALBERT D. WHEELON, *The Ramo-Wooldridge Corporation.*—Isotropic fluctuations of a passive scalar ψ produced by turbulent convection are investigated. The source of irregularities is considered to be the turbulent mixing of an established gradient of ψ. The mixing velocity field is described by Heisenberg's spectrum for homogenous, isotropic turbulence. Replacing the (self-mixing) transfer of energy down the spectrum by an equivalent diffusion term, the local fluctuation spectrum becomes

$$S(k) = (\nabla\psi)^2\frac{1}{k^3}\frac{1}{[1+(k/k_s)^4]^{1/3}}\frac{1}{[1+(k/k_s)^{4/3}]^2},$$

where k_s is the viscosity cut-off wave number of the velocity field. In the similarity range ($k \ll k_s$) this result agrees with the spectrum deduced from purely dimensional arguments. Support for the above spectrum comes from the scattering of radio waves by dielectric fluctuations in the troposphere and ionosphere.

Q4. Scattering of Neutrons by Slightly Imperfect Gases.* ROBERT M. MAZO, *University of Chicago.*—In recent studies of slow neutron scattering by molecules[1] the translational degrees of freedom were treated as those of an ideal gas. We show that the differential cross section can be expanded in a power series in the density of the gas, the first term of which is the previously known result. The higher terms contain integrals analogous to the virial coefficients. The cross section for scattering with energy transfer ϵ is proportional to the time fourier transform of $\langle e^{i\mathbf{k}\cdot\mathbf{r}_\nu(t)}e^{-i\mathbf{k}\cdot\mathbf{r}_{\nu'}(0)}\rangle_T$, where $\mathbf{k}$ is the momentum transfer, $\mathbf{r}_\nu(t)$ is the Heisenberg position operator of particle ν, and the average is an ensemble average. For monatomic gases with potential of intermolecular force $V(r)$, the second term in the expansion has been approximately evaluated under conditions in which the statistical averaging may be done classically (room temperature, for example), both for the direct ($\nu=\nu'$) and interference ($\nu\neq\nu'$) scattering. The analysis can easily be formally extended to polyatomic molecules.

* Supported by the U. S. Atomic Energy Commission.
[1] A. C. Zemach and R. J. Glauber, Phys. Rev. **101**, 118, 129 (1956).

Q5. Isotopic Thermal Diffusion Constants for the Noble Gases.* T. I. MORAN AND W. W. WATSON, *Yale University.*—Since thermal diffusion is a second-order effect, measurement of the temperature dependence of the thermal diffusion constant α provides an excellent check on the force law between molecules. Values of α were measured in a "Trennschaukel,"[1] a device which compounds the "two-bulb" process sufficiently to yield large concentration differences with a temperature difference of no more than 90°K. We have measured the α values for normal neon and for argon containing about 10%

argon 36 from 230°K to nearly 700°K. At lower temperatures the α values of neon and argon are respectively about $\frac{1}{2}$ and $\frac{2}{3}$ of the values given by Stier.[3] It is found for both neon and argon that α increases more rapidly with increasing average temperature of the gas than was previously thought. The neon case indicates a Lennard-Jones 6–12 potential with a force constant of 120°K while the argon data agree with the modified Buckingham exp-6 law using a force constant of 210°K. Results will be given for krypton and xenon.

* This work was supported in part by the U. S. Atomic Energy Commission.
[1] K. Clusius and M. Huber, Z. Naturforsch. **10a**, 230 (1955).
[3] L. Stier, Phys. Rev. **62**, 548 (1942).

Q6. Kinetic Theory of Loaded Spheres.* JOHN S. DAHLER, *Wright-Patterson Air Force Base.*—The kinetic theory of a multicomponent system of loaded-sphere molecules is developed in a manner patterned upon that of Chapman and Enskog. We find that the formal theory of such a system is equivalent to that for a mixture of rigid nonspherical molecules whose centers of mass coincide with their centers of symmetry. The kinetic theory of a simple gas of rigid nonspherical molecules has been presented by Curtiss[1] and so the present work is little more than an extension of Curtiss' work to multicomponent systems. This problem is of more than academic interest since it provides a simple explanation of the thermal diffusive enrichment of a mixture such as $O^{16}C^{12}O^{16}$ and $O^{17}C^{13}O^{16}$ where the molecular species differ only in their moments of inertia. A development similar to ours has been independently carried out by Curtiss and Muckenfuss (unpublished) and their results are apparently in complete accord with those presented here.

* Supported in part by the National Science Foundation and the Office of Naval Research and published as University of Wisconsin, Naval Research Laboratory Report WIS-ONR-23, 13 (December, 1956).
[1] C. F. Curtiss, J. Chem. Phys. **24**, 225 (1956).

Q7. Physical Properties of Fine Mixtures. W. S. AMENT, *Naval Research Laboratory* (introduced by G. T. Rado).—Previously[1] we showed that the physical properties $\bar{a}, \bar{b}, \cdots = \{\bar{a}\}$ of a suspension formed by volume fractions f_i of small spherical particles p_i with properties $\{a_i\}$, radii r_i, in a fluid with properties $\{a\}$ were implied in equations $F_j(\{a\}, \{\bar{a}\}) = \Sigma_i f_i F_j(\{a\}, \{a_i\})$ where $A_j = r_i^3 F_j(\{a\}, \{a_i\})$ are the volume-proportional scattering coefficients of p_i isolated in the fluid. Generalizing Landauer's argument,[2] we obtain the implicit formulas $0 = F_j(\{\bar{a}\}, \{\bar{a}\}) - \Sigma_i f_i F_j(\{a\}, \{a_i\})$ for the properties $\{\bar{a}\}$ of fine isotropic mixtures of volume fractions f_i of materials with properties $\{a_i\}$ $(\Sigma_i f_i = 1)$. We give results for (a) Peltier coefficient, (b) Thompson coefficient, (c) electric conductivity, and (d) thermal conductivity for idealized two-phase alloys. Qualitatively, one must know each of a, b, c, d for both phases to predict $\bar{a}$ or $\bar{b}$ for mixture, and measure each of $\bar{a}, \bar{b}, \bar{c}, \bar{d}$ in confirming experiments. We present similarly intertwined results for (c) and Hall constant (R), obtained by perturbation calculation of the appropriate spherical scattering coefficients; the unsolved exact problem is displayed as possibly relevant to magnetic resonance in polycrystals or multidomain systems.

[1] W. S. Ament, Bull. Am. Phys. Soc. Ser. II, **1**, 179, 293 (1956).
[2] R. Landauer, J. Appl. Phys. **23**, 779 (1952).

Q8. On the Theory of Anisotropic Obstacles in Wave Guides and Cavities.* WALTER HAUSER, *Lincoln Laboratory.*—The Schwinger variational method may be used to obtain approximate solutions to the problem of a cavity or wave guide containing materials with tensor electromagnetic properties. With the introduction of an appropriate dyadic Green's function, one obtains a formal solution to the problem in terms of integrals involving the field vectors within the perturbing medium. Stationary expressions from which the integral equations for the fields and their adjoints are derivable have been constructed. The extremal values of the variational expressions represent such quantities as the resonant frequency of the perturbed cavity, the elements of the scattering matrix of an anisotropic obstacle within a guide, or the propagation constant of a wave in a guide partially filled by an anisotropic material.

* The research reported in this document was supported jointly by the U. S. Army, Navy, and Air Force under contract with Massachusetts Institute of Technology.

Q9. Studies on Electrically Exploded Wires. CHARLES P. NASH* AND W. G. MCMILLAN, *University of California, Los Angeles.*—Small diameter (~No. 40) copper wire of 10 cm length is exploded by thyratron switching across 1 μfd at 15–20 kv. When carried out in air this explosion is attended by two distinct shock waves, associated with the phenomenon of two successive current pulses, separated by the well-known "dark pause" which may range from ~10–100 μsec. Although the energy expended in the first pulse is nearly half the total available, the light output during the second pulse is at least 100 times as great. Shock arrival times and velocities in air have been measured differentially employing barium titanate detectors. With the wire in vacuum the dark pause disappears altogether, giving current and voltage oscillograms very similar to those for a bussbar short. Here we also observe the considerable recondensation of the wire material previously reported by Conn. The behavior of 10 cm silver-plated glass rods (1.91 mm o.d.) in air is similar to that for No. 40 wire in vacuum. For 1.45 mm i.d. capillaries 10 cm long and internally silver plated, the single observed pulse decays exponentially corresponding to a resistance of ~8 ohms.

* General Electric, Charles A. Coffin Fellow, 1955–1956.

Q10. Microradiographic Analysis of Micron Systems.* B. L. HENKE, *Pomona College.*—The "contact printing" of images of microscopic material which is laid upon ultra-fine grain photographic plates can yield microgrammes which permit microscopic and microphotometric analysis of systems of micron dimensions. Sufficient absorption signal or contrast can be obtained for these systems when the contact microradiograms are made with the ultra-soft x-radiations in the 10 to 50 A region.[1,2] Standard absorption analysis techniques can be applied to the microradiograms for quantitative micromass and microchemical analysis provided that good mass absorption coefficient data for this radiation region are obtained, and provided that the proper design of the contact microradiographic camera, of the photographic emulsions, and of the microphotometric apparatus is employed. A first report on the work conducted at this laboratory on the theory and practice of contact microradiographic analysis for micron systems will be presented.

* Supported by the Office of Scientific Research, U. S. Air Force.
[1] Arne Engstrom (dissertation) Acta Radiol., Suppl. LXIII (1946).
[2] Henke, White, and Lundberg, J. Appl. Phys. **28**, 98–105 (1957).

Q11. Mechanism of Leakage Current in Electrolytic Capacitors. KURT LEHOVEC, *Sprague Electric Company.*—The leakage current through aluminum oxide electrolytic capacitors arises from electrons injected into the aluminum oxide by discharging negative ions. Diffusion effects seem negligible. Field distribution in the oxide is governed by space charges arising from trapped electrons. Electron concentration at the electrolyte interface is proportional to the square of the local field intensity (neglecting surface charges). The dc current density (i)—voltage (V) relation becomes

$$V/V^* = [1 + (i/i^*)^{\frac{1}{4}}]^{\frac{1}{3}} - 1,$$

indicating a change with increasing voltage from a cubic to a quadratic relationship. Here $V^* = 2kT\epsilon^*\lambda/(3\gamma K\epsilon)$;

$i^* = \epsilon^{*2}\epsilon_0\mu(kT)^2\lambda^2/(2\epsilon\epsilon^2\gamma^2K^2L^3)$; where kT/e: voltage equivalent of temperature; ϵ^*, ϵ: dielectric constants of electrolyte and aluminum oxide; μ: electron mobility; $\epsilon_0 = 8.84\times10^{-14}$ amp sec/v cm; λ: ratio of bulk concentration of ordinary negative ions to those (impurity) ions which can discharge at the oxide interface; K: ratio of electron concentration at interface to that of dischargeable negative ions; $\gamma-1$: ratio of trapped electron concentration to that of free electron concentration; L: thickness of oxide film.

Q12. New Explanation of the Operation of a Capacitor Microphone as a Total Radiation Detector.* MARY L. HARBOLD, *Temple University* (introduced by J. L. Bohn).—A capacitor microphone acts as the variable capacitor of the tank circuit of a simple Hartley oscillator. Incident radiation is chopped by means of a rotating disk at frequencies from 25 to 12 000 cps. The fluctuations in capacitance of this microphone frequency modulate the oscillator and it can then be detected by a standard FM receiver at a convenient distance. Analysis of the instrument was made for a wide range of metal and metal-coated diaphragms, with and without blackened surfaces. Results indicated that the chief cause of the response was an instantaneous surface expansion of the front surface of the microphone caused by the heating from energy absorption. This forward surface motion is of sufficient magnitude to move the entire front electrode toward the light source to produce responses of considerable magnitude in less than a millisecond. Tests at atmospheric and at low pressures showed gas effects were also present but occurred after a longer time interval.

* This work was supported by the Air Force Cambridge Research Center.

Q13. Accuracy Study of Circumlunar Flights. LEON BLITZER* AND ALBERT D. WHEELON, *The Ramo-Wooldridge Corporation*.—Error coefficients for rocket flights about the moon[1] are computed. For this purpose, the rotation of earth and moon about their common mass center is neglected and a generalization of Euler's solution[2] for motion in the field of two gravitating masses exploited. Uncertainties in the distance of closest approach (dca) to the moon are related to errors in the rocket's burnout position and velocity vectors. Errors in the required speed for bound orbits (37 000 fps) scale as 800 miles/1 fps. Velocity direction gives only second-order errors by choosing a minimum energy orbit. A fundamental fractional uncertainty in the earth's equatorial potential GM/R of 2×10^{-6} implies an irreducible error of 300 miles. These values are comparable with the moon's mean radius 1080 miles. It is found that the moon's attraction tends to smooth such errors. The rocket's return-to-earth position (rep) is controlled by the interaction of the moon's field and uncertainties in the missile's "impact parameter" (i.e., dca), as well as uncertainties in the moon's mass. Numerical estimates of these error coefficients will be presented.

* On leave from University of Arizona.
[1] G. H. Clement, "The moon rocket," Rand Corporation (May 7, 1956).
[2] E. T. Whittaker, *Analytical Dynamics* (Cambridge University Press, New York, 1937), p. 97.

FRIDAY AFTERNOON AT 2:00

Shoreham, Main Ballroom

(W. GORDY presiding)

Microwaves and Bands

QA1. Excitation of Molecular Vibration by Collision.* MORRIS SALKOFF AND ERNEST BAUER, *New York University*.—We have calculated the cross section for excitation of the first vibrational state of a hydrogen molecule by collision with another hydrogen molecule using the intermolecular potential employed previously by one of us.[1] The radial wave equation was integrated on the New York University UNIVAC for relevant values of angular momentum l. The results support the previous calculations[1] in that the principal contribution to the cross section comes from relatively large values of l, of the order of 10 to 15. However, in the range of incident kinetic energies 0.5–2 ev the cross section increases approximately linearly with energy above threshold, having a value of approximately 10^{-18} cm^2 at an energy of the order of one ev.

* Supported in part by the U. S. Air Force and the U. S. Atomic Energy Commission.
[1] E. Bauer, J. Chem. Phys. **23**, 1087 (1955).

QA2. Torsion-Rotation Interaction in Symmetric Tops.* S. KRONGELB AND M. W. P. STRANDBERG, *MIT*.—The satellite lines caused by hindered internal rotation have been observed for the $J=0$ to 1 and $J=1$ to 2 over-all rotational transitions in methyl silane (CH_3SiH_3). The results have been compared with Kivelson's treatment of the problem, and good agreement found.[1] A variation in dipole moment with internal torsional state is also expected since the hindering barrier forces apart the two end groups of the molecule when the internal rotational angle deviates from equilibrium. This variation has been observed and is in agreement with the phenomenological theory.

* This work was supported in part by the U. S. Army (Signal Corps), the U. S. Air Force (Office of Scientific Research, Air Research and Development Command), and the U. S. Navy (Office of Naval Research).
[1] D. Kivelson, J. Chem. Phys. **22**, 1733 (1954).

QA3. Micromodulator—a Device for Measuring the Intensity of Microwave Absorption Lines.* R. D. MATTUCK AND M. W. P. STRANDBERG, *MIT*.—An apparatus for determining the absolute intensity of an unknown microwave absorption line up through the K-band region is described. It employs the strong paramagnetic resonance of an organic free radical (di-phenyl trinitrophenyl-hydrazil) as a standard. The radical is placed in a section of wave guide connected in series with the absorption cell containing the unknown. By varying the applied magnetic field, the free electron resonance may be shifted to any desired frequency. A method of narrowing the standard line for display, by sweeping the magnetic field, is presented. The equations and measurements required are given, together with a discussion of the accuracy of the method.

* This work was supported in part by the U. S. Army (Signal Corps), the U. S. Air Force (Office of Scientific Research, Air Research and Development Command), and the U. S. Navy (Office of Naval Research).

QA4. Shape of Collision Broadened Absorption Lines in the Microwave and Infrared Domain.* EDWIN K. GORA, *Providence College*.—E. P. Gross has shown that both the Lorentz and the Van Vleck-Weisskopf formula for the shape of collision broadened absorption lines can be derived from a

simplified form of the Boltzmann equation where the collision integral is replaced by a relaxation term of the type $(f-f_M)/\tau$; the expression f_M in this term is assumed to represent an average for the distribution functions of the absorbing oscillators after collisions with the perturbing molecules. If f_M describes an equilibrium state with respect to the instantaneous value of the radiation field, the Van Vleck-Weisskopf formula is obtained, while the Lorentz formula follows from the assumption that no such equilibrium is established. A more general line shape formula has been derived by replacing the usual expression for the collision integral in the Boltzmann equation, which is valid for instantaneous collisions only, by an expression permitting time-averaging over the duration of the collision. For low frequencies this line shape formula reduces to the Van Vleck-Weisskopf formula, and for high frequencies to the Lorentz formula. For atmospheric absorption lines the transition between these two line shapes is to be expected at frequencies of several hundred thousand megacycles.

* Supported by the Air Force Cambridge Research Center.

QA5. Modulation Method for Observing Infrared Absorption Spectra.* JAMES C. GILFERT AND DUDLEY WILLIAMS, *The Ohio State University*.—The total integrated absorption of a strong spectral line of Lorentz shape is proportional to the square root of the product of the total pressure P and the absorber concentration w in an absorption cell of fixed length at a fixed temperature.[1] This phenomenon has been used as the basis of a modulation technique for studying infrared absorption of gases. The parameters P and w in an absorbing sample are varied periodically at a low frequency by means of a bellows arrangement attached to the cell, thereby varying the total absorption of each line. The consequent periodic variation in the intensity of the dispersed radiation reaching the detector in a spectrograph produces a periodically varying voltage that can be amplified by conventional techniques. This modulation method has been used to map the spectra of several of the less common atmospheric gases such as N_2O, CO, and CH_4. Typical tracings will be shown, and advantages and disadvantages of modulation techniques will be discussed.

* Supported by a contract between the Air Force Cambridge Research Center and The Ohio State University Research Foundation.
[1] Howard, Burch, and Williams, J. Opt. Soc. Am. **46**, 237 (1956).

QA6. Fundamental of $N^{15}O$.* WILLIAM H. FLETCHER AND GEORGE M. BEGUN, *Oak Ridge National Laboratory*.—The absorption spectrum of the fundamental of nitric oxide was observed with a sample containing 94% of N^{15}. All but two of the spin doublets and part of the rotational structure of the Q branch were resolved. The molecular constants are: $^2\pi_{\frac{1}{2}}$: $B_{01}=1.6146$ cm^{-1}, $B_{11}=1.5984$ cm^{-1}, $D_{01}=D_{11}=3\times10^{-6}$ cm^{-1}, $\tilde{\nu}_0=1843.05$ cm^{-1}; $^2\pi_{\frac{3}{2}}$: $B_{02}=1.6577$ cm^{-1}, $B_{12}=1.6410$ cm^{-1}, $D_{02}=D_{12}=8\times10^{-6}$ cm^{-1}, $\tilde{\nu}_0=1842.79$ cm^{-1}.

* This paper is based on work performed for the U. S. Atomic Energy Commission.

QA7. Microwave Spectrum of Trimethylamine. D. E. MANN AND DAVID R. LIDE, JR., *National Bureau of Standards*.—The $J=0\rightarrow1$ and $1\rightarrow2$ transitions in trimethylamine, $(CH_3)_3N$, have been measured. The lines from molecules in the ground vibrational state follow the expected symmetric-rotor pattern. Molecular constants in the ground states are: $B=8720.85$ Mc, $D_J=5$ kc, $\mu=0.609$ D, $eqQ=-5.47$ Mc (for N^{14}). Each ground-state transition is surrounded by a number of satellite lines which result from molecules in excited states of torsional oscillation. The interpretation of the satellite pattern will be discussed.

QA8. Anomalous Rotational Spectrum in Tm^{171}.* E. N. HATCH† AND F. BOEHM, *California Institute of Technology*.—It has been shown recently[1] that Tm^{171} exhibits an anomalous rotational band characteristic of a $K=\frac{1}{2}$ ground state with striking similarity to the rotational spectrum in Tm^{169}. In order to compare the rotational parameters of the $K=\frac{1}{2}$ band in Tm^{171} with values obtained previously[2] for Tm^{169}, precision measurements of the gamma rays emitted following the 7.5-hour beta decay from Er^{171} have been carried out with the two-meter curved-crystal spectrometer. The measured gamma rays have the following energies in kev: 5.06 ± 0.05, 12.40 ± 0.05, 111.63 ± 0.02, 116.69 ± 0.03, 124.03 ± 0.03, 210.62 ± 0.15, 284.9 ± 0.7, 295.97 ± 0.15, 308.37 ± 0.15. The energies of the two low-energy gamma rays were obtained using the semicircular beta-ray spectrometer. From these measurements the following constants were computed for the $K=\frac{1}{2}$ rotational band: decoupling parameter, $a=-0.8563$; rotational splitting constant, $\hbar^2/2J=11.631$ kev; second-order correction term, $E_{\frac{1}{2}}^{(3)}=+0.02965$. Comparing these parameters with those in Tm^{169}, it is of interest to notice that the relatively large change of a cannot be accounted for entirely by the small change in nuclear deformation. Transition intensities and other features of the level scheme will be discussed.

* Work supported by the U. S. Atomic Energy Commission.
† Present address: Brookhaven National Laboratory, Upton, Long Island, New York.
[1] S. D. Koički and A. M. Koički, Bull. Inst. Nuclear Sci. Boris Kidrich **6**, 1 (1956). Cranston, Bunker, Mize, and Starner, Bull. Am. Phys. Soc. Ser. II, 1, 389 (1956). S. A. E. Johansson (private communication).
[2] Hatch, Boehm, Marmier, and DuMond, Phys. Rev. **104**, 745 (1956).

QA9. Submillimeter Wave Spectroscopy: ND_3.* GUNNAR ERLANDSSON† AND WALTER GORDY, *Duke University*.—The $J=0\rightarrow1$ rotational transition of $N^{14}D_3$ has been measured in the region of 0.97-mm wavelength. Superimposed upon the rotational spectrum is an inversion splitting and a N^{14} nuclear quadrupole hyperfine splitting. The two components of the inversion doublet were observed at 306 735.0 Mc and 309 909.35 Mc/sec. The difference in these frequencies, $\Delta\nu=3174.4$ Mc/sec, represents the sum of the inversion splitting of the $J=0$ and $J=1$ levels. The value of $B_0=154\,162.7$ Mc/sec is obtained from the arithmetic mean of the two components and the infrared value of D_J, 3.4 Mc/sec. The B_0 is consistent with the value 1.0144 A and 107° for the bond length and bond angle. A tentative value for $eQq(N^{14})$ is -4.20 ± 0.15.

* Supported by the Office of Scientific Research, U. S. Air Force.
† Permanent address: University of Stockholm.

QA10. Submillimeter Wave Spectroscopy: DCl.* MONROE J. COWAN AND WALTER GORDY, *Duke University*.—The $J=0\rightarrow1$ rotational transitions in DCl^{35} and DCl^{37} have been measured in the wavelength region of 0.93 mm. Nuclear hyperfine structure was observed for both the Cl and D nuclei. Preliminary results are

	For DCl^{35}	For DCl^{37}
$\nu_0(J=0\rightarrow1)$ in Mc/sec	323 295.70±0.65	322 349.48±0.65
B_0 in Mc/sec	161 656.09	161 182.93
r_0 in A	1.28125	1.28124
B_e in Mc/sec	163 340.1	162 859.0
r_e in A	1.27462	1.27463
eQq(Cl) in Mc/sec	−67.3	−53.1

The values of r and of B employ the infrared D_0 and α_e values by Pickworth and Thompson.[1] Measurements and analysis of the deuterium hyperfine structure are not yet complete.

* Supported by the Office of Scientific Research, U. S. Air Force.
[1] J. Pickworth and H. W. Thompson, Proc. Roy. Soc. (London) **A218**, 37 (1953).

QA11. Precision Measurements of Millimeter and Submillimeter Wave Lines of CO.* WALTER GORDY AND MONROE J. COWAN, *Duke University*.—The $J=0\rightarrow1$ line of CO was the first spectral transition measured in the 2–3 mm wave region. Further improvements in harmonic generators and detectors have made possible more precise measurements of this and higher rotational transitions occurring in the submillimeter region with a video-type spectrometer employing a

slow sweep and high fidelity amplifier. We have obtained

$$\nu_0(J=0\rightarrow 1)=115\,271.195\pm 0.015 \text{ Mc/sec}$$
$$(J=1\rightarrow 2)=230\,537.974\pm 0.030 \text{ Mc/sec}$$
$$(J=2\rightarrow 3)=345\,795.900\pm 0.090 \text{ Mc/sec}$$

for $C^{12}O^{16}$ in the ground vibrational state. These yield

$$B_0=57\,635.965\pm 0.008 \text{ Mc/sec}$$
$$D_0=0.1838\pm 0.0005 \text{ Mc/sec}.$$

From infrared wavelength measurements, Rank has obtained $B_0=1.922521\pm 0.0000035$ cm^{-1} for $C^{12}O^{16}$. The ratio of our B_0 value to his yields the velocity of light as

$$c=299\,793.7\pm 0.6 \text{ km/sec}$$

which is in good agreement with the value, $c=299\,793.0\pm 0.3$ km/sec, recommended by DuMond and Cohen. Actually the microwave B_0 of $C^{12}O^{16}$ is now known to an accuracy better than that of c, and further improvement in the infrared measurements could lead to a significant improvement in the value of the velocity of light.

* Supported by the Office of Scientific Research, U. S. Air Force.

QA12. Velocity of Light Derived from Spectroscopic Measurements on Carbon Monoxide. D. H. Rank, *Pennsylvania State University.*—Wavelengths of 34 lines of the 0→2 band CO have been measured by an interferometric method. $13\Delta_2F''$ values have been obtained over a range of J values from 1 to 29. The analysis of data yields a D_0 value of $6.117\times 10^{-6}\pm 0.01\times 10^{-6}$ cm^{-1}. The final value of B_0 obtained was 1.922521 ± 0.0000035 cm^{-1}. When the infrared B_0 is combined with the B_0 obtained by microwave methods by Gordy[1] and Nethercot and Rosenblum[2] the velocity of light $c=299\,793.8\pm 0.6$ km/sec. The value of D_0 measured in this investigation agrees within experimental error with the latest highly precise microwave determination of D_0 communicated by Gordy.[1]

[1] W. Gordy (private communication).
[2] A. H. Nethercot and R. Rosenblum, Columbia Radiation Laboratory, Third Quarterly Report, 1956.

QA13. Millimeter Wave Cell for Precision Measurements of Both π and σ Stark Components.* Brojo Bhattacharya, Walter Gordy, and Otomi Fujii, *Duke University.*—A parallel plate Stark cell has been constructed which allows precision measurements of both $\Delta M=0$ and $\Delta M=\pm 1$ Stark components of molecular transitions occurring in the shorter millimeter wave region. Precise measurements have been made on HCN for both the $\Delta M=0$ and $\Delta M=\pm 1$ components and for low, intermediate, and high field values. Nuclear magnetic coupling has been detected and measured in HCN, and a more precise value for the N^{14} quadrupole coupling has been obtained. A description of these results will be given.

* Supported by the Office of Scientific Research, U. S. Air Force.

Friday Afternoon at 2:00

NBS, East Building

(I. Estermann presiding)

Solid-State Physics IV, Mostly Metals

R1. An Electron Microprobe for Local Analysis by Means of X-Rays.* David B. Wittry, Jesse W. DuMond, and Pol Duwez, *California Institute of Technology.*—Castaing[1] has demonstrated that it is possible to determine the composition of volume elements of the order of 5 to 10 cu μ at the surface of an alloy by measurement of the intensity of characteristic x-radiation produced under the impact of an electron beam which has been focused to a fine probe. The intensities of the x-rays, when corrected for continuous background, self-absorption in the target, fluorescence excitation, etc., can be related to the mass concentration of elements present in the target with minimum recourse to standards. The accuracy of the method is about 1% for elements present in the region bombarded if the concentration is greater than about 1%. An instrument for local analysis based on this method has been developed. The electron probe is formed by focusing the crossover from a self-biased triode electron gun by means of magnetic electron lenses. Using a single reducing lens, a current of 0.1 μa has been obtained on a spot 5μ in diameter. The x-rays are analyzed by means of a vacuum x-ray spectrometer which uses a curved quartz crystal. In this instrument, the gate of the detecting system is controlled by the integrated target current.

* This work was initially supported by Watertown Arsenal Army Ordnance Corps and is now supported by the Office of Ordnance Research.
[1] R. Castaing, doctoral thesis, University of Paris (1952).

R2. X-Ray Determinations of Debye Temperatures in the Alloy β-AuZn. M. Schwartz and L. Muldawer, *Frankford Arsenal and Temple University.*—Debye temperatures of gold and zinc in β-AuZn were determined at room temperature by a measurement of a number of x-ray reflections from a single crystal. The method employed assumed that interpolated integrated intensities of fundamental and super-lattice lines may be added and subtracted at the same Bragg angle. From the slopes of e^{-M} *vs* $\sin^2\theta/\lambda^2$ the θ_0's were determined to be 159°K for gold and 229°K for zinc. These values seem to be somewhat lower than average accepted values for pure gold and pure zinc. The root mean square value of the amplitude of vibration is larger for the zinc. The same data was used to determine an average θ_0 by assuming a single temperature factor containing a simple average mass. Super-lattice points were found to lie above and fundamental points were found to lie below the straight line plot of e^{-2M} *vs* $\sin^2\theta/\lambda^2$. A θ_0 of 190°K was obtained. Use of reduced mass gives 219°K. If one assumes additivity of specific heats and also θ_0's for pure gold and pure zinc of 159°K and 229°K, respectively, a θ_0 for the alloy of 182°K is obtained. This result is insensitive to the value of θ_0 for zinc. These results will be compared with those obtained for Cu_3Au.

R3. Elastic Constants of Zinc Single Crystals.* Maurice Croutzeilles and Edward A. Stern, *California Institute of Technology.*—The five elastic constants of zinc single crystals have been measured from liquid nitrogen to room temperature. An ultrasonic resonance technique with electrostatic drive, similar to that of Pursey and Pyatt,[1] is utilized. The electrostatic drive does not require mechanical contact between exciter and specimen, and thus is particularly suitable for measurements as a function of temperature since there is no stress produced by differential thermal expansion between the specimen and exciter. The problem of the propagation of elastic waves along an infinite cylinder composed of an anisotropic hexagonal crystal whose c axis is also the axis of the

cylinder was solved exactly. Using this solution, it is possible in principle to measure all five elastic constants of a hexagonal crystal by measuring the variation of velocity of longitudinal waves as a function of frequency. In practice three constants were obtained this way, while the other two were obtained by measurements on two other differently oriented crystals.

* This work was supported by the Office of Scientific Research, U. S. Air Force.
[1] Pursey and Pyatt, J. Sci. Instr. **31**, 248 (1954).

R4. Temperature Variation of Elastic Constants.* EDWARD A. STERN, *California Institute of Technology*.—By considering the quantum mechanical behavior of a particle acted upon by an anharmonic potential well, a method is developed which permits the calculation of the temperature variation of the adiabatic elastic constants. This method is applicable to any solid, since it does not require central forces between atoms. It is in contrast to the method of Born and his collaborators[1] which assumed a special central force between atoms. Using the calculation of Fuchs[2] on the elastic constants of Na and Li, the temperature variations of the adiabatic elastic constants of Na and Li are calculated from 0°K to room temperature, neglecting their respective allotropic transformations at 32°K and 78°K.[3] The calculation for Na is compared with experiment in the temperature range of the measurements.[4]

* This work was supported by the Office of Scientific Research, U. S. Air Force.
[1] M. Born and M. Bradburn, Proc. Cambridge Phil. Soc. **39–40**, 104 (1943–1944).
[2] K. Fuchs, Proc. Roy. Soc. (London) **151**, 585 (1935); **153**, 622 (1936); **157**, 444 (1936).
[3] C. S. Barrett, Phys. Rev. **72**, 245 (1947); J. Inst. Metals **84**, 43 (1955).
[4] S. L. Quimby and S. Siegel, Phys. Rev. **54**, 293 (1938).

R5. Elastic Constants of Magnesium from 4.2°K to 300°K.* C. W. GARLAND AND L. J. SLUTSKY, *MIT*—The elastic constants of Mg have been measured using an ultrasonic pulse technique. The values at 298°K are $c_{11}=0.594$, $c_{33}=0.616$, $c_{44}=0.164$, $c_{13}=0.256$, $c_{12}=0.213$ in units of 10^{12} dyne cm^{-2}. These are in good agreement with the recent values of Long and Smith.[1] The values extrapolated to 0°K are $c_{11}=0.634$, $c_{33}=0.661$, $c_{44}=0.184$, $c_{12}=0.259$, $c_{13}=0.213$. A Debye characteristic temperature, $\theta_D=385$°K, has been calculated at 0°K using the mean values of the longitudinal and transverse wave velocities. The experimental value of θ_D is 406 ± 10°K.[2] Atomic force constants for a central force model including an isotropic, volume-dependent electron gas contribution are also obtained from these elastic constants.

* Work supported by the U. S. Army (Signal Corps), the U. S. Air Force (Office of Scientific Research, Air Research and Development Command), and the U. S. Navy (Office of Naval Research).
[1] T. R. Long and C. S. Smith, Acta Metallurgica (to be published).
[2] P. L. Smith, Phil. Mag. No. 7, **46**, 744 (1955).

R6. Strain Scattering in Metals.* LAURA M. ROTH, *Harvard University* (introduced by Benjamin Lax).—The scattering of conduction electrons by the lattice strain about a substitutional impurity, vacancy, or interstitial in a monovalent metal has been calculated, using the Bardeen rigid ion model with screening, and using the Ewald method for the lattice sum involved. It is found that for substitutional impurities representing relatively weak scattering potentials, the strain scattering can be important. In the case of interstitials, the strain scattering may be of the same order of magnitude as that from the interstitial itself, because of the large lattice displacements. The results for noble metals are somewhat larger than the estimates made by Dexter[1] and are an order of magnitude smaller than the recent calculation of Overhauser and Gorman[2] for vacancies and interstitials in Cu.

* Now at Lincoln Laboratory, MIT.
[1] D. L. Dexter, Phys. Rev. **87**, 768 (1952).
[2] A. W. Overhauser and R. L. Gorman, Phys. Rev. **102**, 676 (1956).

R7. Shock Waves in Metals Generated by Projectile Impacts.* D. S. HUGHES, W. M. OTTO, E. B. BLANKENSHIP, MARY F. GOURLEY, AND L. E. GOURLEY, *University of Texas*.—A gun with a bore of 41 mm and a barrel length of 150 cm is used to fire flat-ended projectiles into thin flat targets. The projectiles are driven by helium pumped into a gas chamber behind the projectile until holding threads shear. The target is mounted in a chamber at the end of the barrel which is evacuated to 5–10 μ. The projectile velocity is measured by contact pins of graduated lengths. The free surface velocity of the target after impact is measured by recording the impedance of a small condenser plate mounted a few thousandths of an inch off the target face. Projectile velocities of 0.0050 to 0.100 cm/μsec have been used. The results show the final free surface velocity of the target to be somewhat less than the projectile velocity. The measured elastic wave velocity in 24ST aluminum is 0.64 cm/μsec. The pressure in the elastic wave varies from about 2.7 to 7.5 kilobars depending on the projectile velocity. After the elastic wave arrival the free surface accelerates for about 0.3 μsec; after this its velocity is essentially constant.

* This work was sponsored by the National Science Foundation and the American Petroleum Institute.

R8. Bulk Density of Separated Lithium Isotopes.* D. D. SNYDER AND D. J. MONTGOMERY, *Michigan State University*.—As part of a program exploiting isotopic mass as a probe for solid-state investigations, the bulk density of extruded specimens of natural lithium and of enriched isotopes† (>99%) was measured by flotation and by loss of weight. Upon correction for the slight chemical impurities and upon reduction to 20°C, the following results were obtained for the bulk density in gm/cm^3: lithium-6 (adjusted to 100% Li^6), 0.460 ± 0.003; lithium-7 (adjusted to 100% Li^7), 0.537 ± 0.002; lithium-natural (abundance ratio 7.5% Li^6, 92.5% Li^7), 0.531 ± 0.001. The crystal densities, calculated from the lattice constants determined by x-ray diffraction,[1] are respectively 0.462, 0.539, 0.533. In each case the bulk density is about half a percent lower than the crystal density, in contrast with the finding of Richards and Brink[2] that the bulk density of natural lithium is 0.534, slightly higher than the crystal density.

* This work was supported in part by the U. S. Atomic Energy Commission.
† We are indebted to the Stable Isotope Research and Development Division, ORNL, for loan and analyses of the enriched samples, especially to Dr. P. S. Baker for his assistance and advice. The All-College Research Fund of Michigan State University provided the loan fees for the initial investigations.
[1] D. J. Montgomery and E. J. Covington, Fifth Annual Midwest Solid State Conference, Chicago, October 6, 1956.
[2] T. W. Richards and F. N. Brink, J. Am. Chem. Soc. **29**, 120 (1907).

R9. Field Emission Microscope Studies of Zr on Mo.* R. C. BRADLEY AND E. C. McIRVINE, *Cornell University*.—The field emission microscope has previously been used to investigate the surface conditions of an alloy of a few percent of zirconium in molybdenum.[1] The results were interpreted on the basis of a volume diffusion process for which an activation energy was measured. To test this interpretation Zr was evaporated onto a pure Mo field emission point and an activation energy for surface migration was measured. The agreement between measured activation energies plus the similarities in the emission patterns obtained in the two different ways suggest that in the case of the alloy the rate controlling mechanism was also surface migration, the Zr coming from sources (presumably grain boundaries) along the shank of the point. It is thought that the initial high temperature flash, used primarily to clean the emitting surface of the alloy, also serves to replenish these sources. Activation energies for desorption of Zr from both the Mo and the alloy surface have also been obtained and are in good agreement.

* This research was supported by the U. S. Air Force through the Office of Scientific Research of the Air Research and Development Command.
[1] L. A. D'Asaro, Phys. Rev. **100**, 1258(A) (1955).

R10. Some Electrical Resistance-Strain Characteristics of Thin Evaporated Films.* A. KRINSKY AND R. L. PARKER, *National Bureau of Standards* (introduced by H. P. R. Fred-

erikse, N.B.S.).—Thin films of a number of metals, alloys, and semiconductors have been deposited by vacuum evaporation onto insulating bases and tested for change of electrical resistance under applied stress. For a number of metals, the film strain-sensitivity has been found to be a function of film thickness. For films in the vicinity of 1000-au thickness, the strain-sensitivity approaches the known bulk wire value. For somewhat thinner films the strain sensitivity is considerably less than the bulk value; but for yet thinner films (specific resistances from approx 10^3 to 10^6 ohms per square, thicknesses from approx 100–200 au to 50 au), it is several times the bulk value. The resistance *vs* strain characteristic is linear except for Ni and Sb. The nonlinearity in Ni films of approx 1000-au thickness is similar to the known bulk wire nonlinearity; for progressively thinner Ni films the nonlinearity disappears. The known semiconducting-like characteristics of thinner evaporated films (in which the required activation energy is ascribed to the granular structure of the films) may account for some of the behavior observed.

* This work is part of a program on basic instrumentation research and development sponsored by the U. S. Atomic Energy Commission, the Department of the Navy, and the Department of the Air Force.

R11. Surface Study of Evaporated Aluminum by X-Ray Total Reflection Method.* R. C. Duncan, Jr., and L. G. Parratt, *Cornell University.*—Aluminum films 5000 A thick, evaporated onto optically flat Pyrex glass substrates, have been studied by the x-ray total reflection method.[1] Somewhat different rates of evaporation and different residual gas pressures were used. Five films were subjected to repeated heat treatments in atmospheric air at temperatures up to 400°C for periods up to 12 hours. Without exception they showed a marked and progressive drop in x-ray reflectivity over the entire "total" reflection region, accompanied by a very slight decrease in the critical angle and by the appearance of patches of blister-like spots over a large portion of the film surface. The most pronounced decrease in reflectivity occurred at small glancing angles, producing there a reflectivity minimum which grew progressively deeper with successive heatings. Similar films, aged at room temperature or oxidized by anodization, exhibited no such effects. The anodized film showed an increasing critical angle approaching that expected for the higher density oxide. Various sensitive parameters of the changing reflection curves appear to be better correlated with number of heatings than with temperature or length of heat treatment. The observed effects lack detailed theoretical interpretation as yet.

* This work was supported in part by the U. S. Air Force through the Office of Scientific Research of the Air Force Research and Development Command.

[1] L. G. Parratt, Phys. Rev. **95**, 359 (1954).

R12. Surface Study of Evaporated Copper by X-Ray Total Reflection Method.* Nancy J. Scott and L. G. Parratt, *Cornell University.*—The method described in the previous abstract has been applied to the study of thin copper films (35 to 150 A thick) evaporated onto glass substrates. Contrary to observations with soft glass substrates, similar "fresh" copper films on Pyrex do not show a minimum near the critical angle. Films of 75, 120, and 150 A on Pyrex were subjected to successive heat treatments up to 400°C in laboratory air. After treatment to about 130°C, the critical angle θ_c was observed to be greatly reduced, even well below the value predicted for Cu_2O on glass. Then, continued heat treatments above about 200°C caused θ_c to increase slightly to an apparent saturation value. Similar treatments with 75 A films on soft glass caused the minimum near the critical angle to "wash out" completely by the time θ_c reached its minimum value. A pronounced low-angle dip, as observed for aluminum (see previous abstract), developed at 300°C for films on soft glass substrates only and became progressively deeper with additional heat treatments. Theoretical dispersion calculations based on the simplest film model (having uniform density) predict only the qualitative shape of the reflection curve for either fresh or heat treated films.

* This work was supported in part by the U. S. Air Force through the Office of Scientific Research of the Air Force Research and Development Command.

R13. Adsorption of Nickel on Molybdenum in the Field Emission Microscope.* E. C. McIrvine and R. C. Bradley, *Cornell University.*—The adsorption characteristics of Ni on clean Mo surface have been investigated using a sealed-off field emission tube with provisions for evaporating Ni onto the Mo emitter. The location of adsorbate agrees with predictions based on the geometrical fit of coherently adsorbed material. Activation energies for desorption (Q_d) and surface migration (Q_m) were determined for coverages $\sim$0.2 monolayer. The experimental Q_d is the minimum Q_d for any region of the emitter, 2.10 ± 0.05 ev. In the surface migration case, the experimental Q_m varies according to the degree of completion of the migration process: 1.31 ± 0.08 ev ($\frac{1}{4}$ completed), 1.42 ± 0.05 ev ($\frac{1}{2}$ completed), and 1.48 ± 0.06 ev ($\frac{3}{4}$ completed). For heavier coverages of adsorbate, builtup areas were observed which gave enhanced emission. At an elevated temperature which allowed migration, the equilibrium position of these areas changed reversibly upon application of the field. Other observations of heavy adsorbed layers will be presented.

* Supported by the U. S. Air Force Air Research and Development Command.

Friday Afternoon at 2:00

Shoreham, West Ballroom

(F. N. Frenkiel presiding)

Fluid Dynamics

RA1. Rate of Saturation of Solutions in Capillaries. Peter K. Weyl, *Shell Development Company.*—The rate at which saturation is reached in a solution flowing through a circular capillary by laminar flow in a slightly soluble solid has been determined theoretically. It is assumed that the solution in contact with the wall is always saturated and that the rate of solution depends only on the rate of diffusion away from the wall. The problem is identical to the problem of heat transfer from a pipe to water flowing in it. The first term of the series expansion of the general solution is

$$\bar{C}' \approx 0.67 \exp -\tfrac{1}{2}[(v/D)^2 + (2/a)^2]^{\frac{1}{2}} - v/D\}z,$$

where $\bar{C}'$ is the average fractional difference from saturation, v is the average fluid flow velocity, D is the diffusion constant, a is the radius of the capillary, and z is the distance in the capillary. The distance at which the solution is 90% saturated

is $0.572va^3/D$ for conditions of rapid flow ($va/D \gg 1$), and $0.96a$ when the flow velocity is small ($va/D \ll 1$). Data will be presented which indicate that the rate of solution of calcite is not inconsistent with the above model.

RA2. Taylor Instability—Numerical Calculations. G. BING, R. E. LELEVIER, AND W. NOH, *University of California, Livermore*, AND L. G. HENYEY, *University of California, Berkeley.*—The instability of an incompressible, irrotational, and inviscid fluid of finite thickness is being investigated numerically. The properties of the fluid are expressed by two nonlinear partial differential equations, the dependent variables being the X and Y position coordinates of any particle of fluid. The condition of constant pressure on the free surface (s) is given by a somewhat novel form of Bernoulli's equation. The top of the fluid is taken as either a rigid surface (with slip) or as another free surface. For the side conditions we invoke periodicity. The partial differential equations are approximated by finite difference equations correct to second order in the time interval and grid spacings. Thus, for a K by L grid we have $2KL$ coupled, nonlinear equations in $2KL$ unknowns which connect the fluid properties at time $t+\Delta t$ with those at time t. These equations are solved by a Newton's method in the $2KL$ variables. The *numerical* instability of the difference equations is controlled by an artificial, nonlinear surface tension at the free surface (s). Results will be presented and extensions to the case of two fluids in contact will be discussed.

RA3. Electrical Conductivity of Thermally Ionized Air Produced in a Shock Tube.* LAWRENCE LAMB AND SHAO-CHI LIN, *AVCO Research Laboratory.*—The electrical conductivity of shock-heated air at equilibrium temperatures from 3500°K to 6200°K, and at air densities of the order of 0.01 N.T.P., has been measured, using the shock wave magnetic field interaction technique reported by Lin, Resler, and Kantrowitz.[1] The experimental results indicated that the ionization process built up quickly behind the shock front, and that the measured conductivity agreed quite well with calculated values based on the equilibrium degree of ionization, the electron diffusion cross sections for the molecular species available in the literature, and on a theoretical estimate of the cross sections for oxygen and nitrogen atoms by Hammerling, Kivel, and Shine.[2]

* This work has been supported by the U. S. Air Force.
[1] Lin, Resler, and Kantrowitz, J. Appl. Phys. **26**, 95–109 (1955).
[2] Hammerling, Kivel, and Shine, "Low-energy elastic scattering of electrons by oxygen and nitrogen" (to be published).

RA4. Possible Explanation of the Reversal of Boundary Layer Transition. A. M. SAPERSTEIN, *University of Michigan.*—As the wall temperature of a cone is decreased, it is expected that the distance from the tip to the point of turbulent transition will increase. Experiments of Evvard[1] have shown that at low enough temperatures, a reversal takes place such that further decrease in temperature leads to a decrease in the tip-transition point distance. A very simple explanation of this anomaly may be given by assuming that the increasing temperature difference between the wall and the boundary layer gives rise to large transverse heat convection currents. The current velocity may increase to the point where the critical Reynolds number is again surpassed. Assuming a current linear in the temperature difference, it is found that the wall temperature varies approximately as the negative inverse of the transition distance, a variation similar to that found by Evvard.

[1] J. C. Evvard, Bull. Am. Phys. Soc. Ser. II, **2**, 27 (1957).

RA5. Mutual Reflection of Two Shocks of Arbitrary Strengths.* W. R. SMITH, *Princeton University.*—The interaction of two weak shock waves of equal strength was studied experimentally. The weak solution of the two-shock theory agreed with the regular reflection data, but the three-shock theory did not agree with the Mach reflection data. The Mach reflection data showed that the differential dependence of χ on α predicted by a local theory was incorrect. Data on the transition from regular to Mach reflection indicated that regular reflection terminates very near the extreme angle α_e and does not persist beyond it. Four sets of experiments on the interaction of two shock waves of unequal strengths were performed and the data compared with the results of graphical shock polar calculations made for each set. The weak regular solutions agreed with the regular reflection data. The Mach reflection data did not agree with the three-shock theory. The data on the transition from regular to Mach reflection were consistent with the conclusion that regular reflection does not persist beyond the extreme angle.

* Supported by the Office of Naval Research.

RA6. Velocity Attenuation on Strong Shocks in Air. S. W. KASH, J. GAUGER, W. L. STARR, AND V. VALI, *Lockheed Missile Systems Division.*—Velocity measurements have been carried out on magnetically driven shock waves produced by discharging a two microfarad bank of condensers charged to 40 kv (1600 joules) into a "tee-type" discharge tube.[1] The dependence of velocity on ambient pressure within the tube and shock attenuation measurements up to approximately one meter from the discharge have been made for ambient pressures ranging from 1 to 20 mm of air. Several techniques for changing the magnetic coupling between the discharge circuit and the gas have been employed and the results of these efforts will be reported. The velocity measurements have utilized photomultiplier arrangements for recording the passage of the luminous gas at several stations along the shock tube.

[1] Fowler, Goldstein, and Clotfelter, Phys. Rev. **82**, 879 (1951).

RA7. Hydromagnetic Shock Tube.* V. H. BLACKMAN, G. B. F. NIBLETT, AND G. SCHRANK, *Princeton University.*—Strong shock waves have been produced by discharging a low inductance capacitor (1.6 μf, 25 kv, 0.025 μh) through a coil wrapped around a 1-inch diameter quartz tube containing gas at reduced pressure. The rapidly varying magnetic field (70 kilogauss/μsec) breaks down the gas and induces circular current loops. Shock waves, moving outward from the coil, are generated by the rapid expansion of the gas due to joule heating and the interaction of the magnetic field with the current loops. The largest component of the magnetic force is directed inward toward the axis of the tube and there is evidence that the highest temperatures occur along the axis. Streak photographs show Mach numbers $M > 50$ for pressures of 1 mm air and $M > 200$ for pressures of 0.2 mm air at a distance of 3 cm from the coil; this velocity decays rapidly. Results will be presented showing the variation of Mach number with nature of the gas, gas pressure, and circuit parameters. Attempts are underway to propagate the shock without attenuation by using several coils along the tube fired in succession.

* This work is supported by the Office of Naval Research.

RA8. Radiative Relaxation behind a Shock Wave.* JOHN CAMM AND JAMES KECK, *AVCO Research Laboratory.*—The optical radiation emitted from air heated by a shock wave is being studied as a function of distance behind the shock front with the general objective of obtaining information about various chemical and electronic rate processes. The experimental apparatus consists of a system of collimating slits which define a narrow beam perpendicular to the shock tube axis, a monochromator for selecting various wavelength bands, and a photomultiplier for recording the signal as a

function of time as the shock wave moves past the collimating slits. Preliminary observations show that the intensity of the radiation behind a Mach 15 shock in air at 1 mm pressure rises extremely rapidly and goes through a maximum in a distance of less than 0.25 mm, the limiting resolution for our apparatus. It then decays monotonically in a distance of the order of a centimeter to a final steady state value. There is evidence from the spectral distribution of the radiation that this "luminous front" in air is not an impurity effect as in the case of argon. If one makes certain tentative assumptions, the recombination rate constant at 6000°K turns out to be: $k_R \sim 2\times10^{16}$ cm^6 moles^{-2} sec^{-1}.

* This work supported by U. S. Air Force.

RA9. Approach to Thermal Equilibrium behind Strong Shock Waves in CO_2 and CO.* W. D. GREENSPAN AND V. H. BLACKMAN, *Princeton University.*—The adjustment to equilibrium of the vibrational modes of the CO_2 molecule has been investigated in the shock tube using an interferometer to observe the density profile across the shock wave. Shocks ranging from $M_1=4.7$ to $M_1=8.7$ were obtained corresponding to final state temperatures of 1000° to 2500°K. The density ratio ρ/ρ_1 across each shock was measured and a comparison of these experimental points with three curves of ρ/ρ_1 *versus* M_1, each calculated using contributions to the heat capacity from different vibrational modes, gives strong evidence for the existence of three separate relaxation times for CO_2. Present measurements give values of 2 μsec at 600°K for the bending mode adjustment, in agreement with the results of Griffith, and 3.5 μsec at 2200°K for the symmetric valence ν_1 mode, $h\nu_1/k=1920$°K. Relaxation times in CO were also measured over a limited temperature range and vary from 2.7 μsec at 3500°K to 10 μsec at 2200°K. The measured density agrees with the calculated equilibrium value within experimental error.

* This work was supported by the Office of Naval Research.

Invited Paper

RA10. Research in Extreme High-Speed Gas Dynamics Using the Shock-Tube Wind-Tunnel Technique. E. H. WINKLER, *U. S. Naval Ordnance Laboratory.* (30 min.)

FRIDAY AFTERNOON AT 2:00

Sheraton-Park, Caribar-Mural Room

(R. G. FLUHARTY presiding)

Neutron Spectroscopy

S1. ZnS-B_2O_3 Scintillation Detector for Slow Neutrons.* H. R. MUETHER,† H. PALEVSKY, AND R. L. ZIMMERMAN, *Brookhaven National Laboratory.*—A scintillation detector for slow neutrons has been constructed with 2 in. caps made from a fused mixture of ZnS and B_2O_3. Sixty four such caps, each viewed with a single 6292 phototube, are mounted in a bank the size of the neutron beam at the Brookhaven fast chopper. An early model of such a detector[1] was built but found to be difficult to use because of a 25% background resulting from beam neutrons which passed through the caps, were moderated in the tube sockets, and returned to count with higher efficiency in the caps. Disks of pure B_2O_3 glass are placed between the phototubes and the scintillating caps, reducing the background from this source to less than 3%. The present efficiency at 1000 ev is about 0.5%. The theoretical efficiency is 4% and can be approached by eliminating phototube noise, now the principal source of background. The advantage of the scintillation detector over BF_3 proportional counters of similar efficiency is the absence of timing uncertainties arising from jitter and time of flight in the gas.

* Work performed under contract with U. S. Atomic Energy Commission.
† Permanent address: Queens College.
[1] Palevsky, Muether, and Stolovy, Phys. Rev. **93**, 920(A) (1954).

S2. Kilovolt Neutron Cross Sections by Millimicrosecond Time of Flight. J. H. GIBBONS, W. M. GOOD, AND J. H. NEILER, *Oak Ridge National Laboratory.*—Subject at present to the limitation of short ion source lifetime, it is possible by terminal Van de Graaff pulsing to produce close to one microampere (average current) of 8×10^{-9} sec duration bursts of protons at a repetition rate of 10^6/sec. As previously described[1] a pulsed beam such as this can be used with the Li(p,n) reaction for the measurement of total cross sections in the 2–35 kev range. Time resolution can be easily varied so as to maintain a constant percentage energy resolution. An investigation is underway of the cross sections of separated isotopes in the kilovolt region. Results at selected energies for Al, K^{39}, K^{41}, Ti, Fe, Se, Rb^{85}, Rb^{87}, Sr^{86}, Sr^{88}, Y, Pb, and Bi will be presented. Analysis of some of the levels has indicated resonance widths varying from 20 ev in Al (5.5 kev) to 7000 ev in Ti (17 kev).

[1] Smith, Gibbons, Good, Neiler, and Banta, Bull. Am. Phys. Soc, Ser. II, **1**, 71 (1956).

S3. Photoneutron Spectra Using Time-of-Flight Techniques.* W. BERTOZZI,† C. P. SARGENT, AND P. T. DEMOS, *MIT*—A fast pulser has been installed in the Massachusetts Institute of Technology linear accelerator producing γ-ray beams of controllable full widths $\lesssim 4\times10^{-9}$ sec. Neutrons from (γ,n) are detected by proton recoils in a 4×4 in. cylinder of plastic scintillator viewed by three 6810 photomultipliers ~7 m from the γ-ray target. To avoid blocking the detector by the intense scattered γ-ray pulse, the photomultipliers are turned on for a 6×10^{-7} sec interval beginning 10^{-7} sec after the γ-ray pulse. The flight times are converted to pulse heights[1] and recorded on a multichannel pulse-height analyzer which is gated by a proton recoil energy discriminator. Phototube noise and counting rate place the lower limit of detectable neutron energies at ~0.5 Mev. The entire system has a possible energy resolution of ~40 kev for 1 Mev neutrons and ~1 Mev for 10 Mev neutrons. Some preliminary $(\gamma-n)$ spectra will be discussed.

* This work has been supported in part by the Joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.
† Part of this work performed while author was Shell Fellow.
[1] Neiler, Kelley, and Bell, Bull. Am. Phys. Soc. Ser. II, **1**, 70 (1956).

S4. Ratio of Neutron Width to Level Spacing.* R. L. ZIMMERMAN, R. B. SCHWARTZ, AND D. J. HUGHES, *Brookhaven National Laboratory.*—The average of the ratio of the reduced neutron width to the levels spacing, $\langle\Gamma_n^0/D\rangle$, has been measured for a number of elements whose atomic weights range between 91 and 238. The measurements have been made both by analyzing the parameters of individual levels where they can be resolved, and by making total cross-section measurements in the kilovolt energy region[1] where an average over many unresolved levels gives $\langle\Gamma_n^0/D\rangle$ directly. The experimental results show a peak at about $A=155$ which agrees qualitatively with recent calculations[2] using a potential well with a diffuse boundary and the "cloudy crystal ball" model of the nucleus. However, the experimental peak has an amplitude lower by a factor of two than that predicted by theory, and is asymmetric to the extent that although there is quantitative agreement at $A=235$ the experimental points are lower than theory by a factor of four at $A=100$.

* Work performed under contract with U. S. Atomic Energy Commission.
[1] D. J. Hughes and V. E. Pilcher, Phys. Rev. **100**, 1249(A) (1955).
[2] V. F. Weisskopf, Physica **22**, 952 (1956).

S5. *P*-Wave Strength Functions near Mass Number 92.* P. F. NICHOLS, A. K. FURR, AND H. W. NEWSON, *Duke University.*—These strength functions for Se, Sr, Y, Mo, Zr^{91}, Zr^{96}, and Zr^{98} have been calculated from total cross-section curves between about 10 and 100 kev on the following assumptions: The *s*-wave strength functions, $(\bar{\Gamma}_n^0/\bar{D})_{l=0}=10^{-4}$; the effective radius for *s* waves, $R'=R=(1.3A^{\frac{1}{3}}+0.7)\times10^{-13}$ cm; black nucleus barrier penetration factors may be used; *p*-wave shape elastic scattering $=0$; and all neutron widths $\gg$ the capture widths. More complete analysis of As^{75} is possible because of its relatively high level density. All data were corrected for the change of self-protection with energy. At $A=75$ and $A\cong110$ (see the following abstract) the *p*-wave strength function drops to the neighborhood of 10^{-4}. The average strength function for the three Zr isotopes which appear to be at the maximum of the curve is 6×10^{-4}; this high value may be in part the result of an under correction for shape elastic scattering. According to the F.P.W. complex potential square well model, the location of the peak corresponds to a real potential $\cong46.5$ Mev and the Zr strength functions, to an imaginary fraction less than 5%. The maximum in a plot of strength function against A is at the same mass number, 92, as the maximum measured anisotropy in differential cross sections of even-nuclei.

* This work was supported by the U. S. Atomic Energy Commission.

S6. Neutron Activation Cross Sections.* E. G. BILPUCH, L. WESTON, H. W. NEWSON, R. H. ROHRER, AND K. JONES, *Duke University.*—We have measured relative activation cross sections by using Li(p,n) neutrons at 90°. Generally, our samples are in the form of foils $(0.1\times12\times0.001$ in.). In practice these foils are wrapped in the form of a ring 1 in. in diameter and placed in position to intercept the 90° neutrons. The ring is a thin sample for neutron transmission and a thick sample for β transmission. After an exposure the ring is spiraled on a thin-walled β counter in order to make the sample thin to β transmission. We obtain satisfactory counting rates with a proton beam of 5 to 10 μa, a bombardment time of one hour for any heavy nuclide (not too near to a neutron magic number) with an isotopic abundance of the order of 10%, a β-ray energy of about 1 Mev and a half-life of the order of ten days or less. During each exposure, the neutron flux was monitored by a long counter. The efficiency of the long counter as a function of energy (3 to 70 kev) was compared to the (n,α) across section of B^{10}. We find the total cross section of the latter to be $\sigma_T=642/E_n^{\frac{1}{2}}+2.45$ barns. Assuming the first term to be $\sigma_{n\alpha}$, the long counter has flat response to at least 70 kev.

* This work was supported by the U. S. Atomic Energy Commission.

S7. Average Neutron Level Parameters for In and U.* H. W. NEWSON AND E. G. BILPUCH, *Duke University.*—Absorption cross-section curves for In^{115} and U^{238} have been fitted by varying the capture width, Γ_γ, the average neutron reduced width, $\bar{\Gamma}_n^0$, and the average spacing, $\bar{D}$. The *s*-wave parameters which agree within experimental error with known values are as follows: $(\Gamma_\gamma/\bar{D})_{l=0}=5.5\times10^{-3}$, $(\bar{\Gamma}_n^0/\bar{D})_{l=0}=0.31\times10^{-4}$ for In^{115} and $(\Gamma_\gamma/\bar{D})_{l=0}=1.2\times10^{-3}$, $(\bar{\Gamma}_n^0/\bar{D})_{l=0}=1.4\times10^{-4}$ for U^{238}. The best fit to our experimental curves was found by using the Porter-Thomas distribution function on the reduced neutron width and the following *p*-wave parameters: $(\Gamma_\gamma/\bar{D})_{l=1}=(\Gamma_\gamma/\bar{D})_{l=0}$, $(\bar{\Gamma}_n^0/\bar{D})_{l=1}=4(\bar{\Gamma}_n^0/\bar{D})_{l=0}=1.24\times10^{-4}$ for In^{115} and $(\Gamma_\gamma/\bar{D})_{l=1}=3(\Gamma_\gamma/\bar{D})_{l=0}=3.6\times10^{-3}$, $(\bar{\Gamma}_n^0/\bar{D})_{l=1}=1/2(\bar{\Gamma}_n^0/\bar{D})_{l=0}=0.7\times10^{-4}$ for U^{238}. It should be noted that the parameter $\Gamma_\gamma/\bar{D}$ is the same for *s* and *p* neutrons for In^{115} and that for U^{238} the *p* parameter is 3 times the *s* parameter. Since U^{238} has a spin of zero and In^{115} has a spin of 9/2, the variation of the parameter $\Gamma_\gamma/\bar{D}$ would be reasonable if $\bar{D}=D_0/(2J+1)$. This point will be checked further by examining the case of Ag^{107} which has a spin of $\frac{1}{2}$. Other authors have fitted the U^{238} data at higher energies (above 200 kev) by a similar assumption of the dependence of D on the total spin.

* This work was supported by the U. S. Atomic Energy Commission.

S8. Gamma Rays Following Neutron Capture in Titanium. G. MANNING, G. A. BARTHOLOMEW, P. J. CAMPION, AND J. W. KNOWLES, *Chalk River Laboratory.*—Gamma rays following neutron capture in titanium have been investigated in the energy range 2.7 to 11.0 Mev using a pair spectrometer with an energy resolution of 1.0% and in the energy range 0.8 to 2.0 Mev using a flat crystal diffraction spectrometer[1] with an energy resolution of 0.4 to 0.8%. Forty γ rays were detected, twenty of which have not previously been resolved. From consideration of reaction energies the probable assignments for γ rays observed at 10.621 ± 0.014, 6.753 ± 0.005, and 9.376 ± 0.012 Mev are between the capturing states and the 0.990-Mev level of Ti^{48}, the 1.379-Mev level of Ti^{49} and the 1.58-level of Ti^{50}, respectively, whence the corresponding neutron binding energies are determined as 11.611 ± 0.017, 8.132 ± 0.006 and 10.96 ± 0.06 Mev. Previously indicated levels[2] in Ti^{49} can now be quoted with improved accuracy: *viz.*, 1.379 ± 0.003, 1.582 ± 0.010, 1.719 ± 0.003, 3.175 ± 0.008 and 3.261 ± 0.008 Mev. The strength of the observed transitions from the capturing state to the five levels is consistent with the assumption that the spins of these levels are $\frac{1}{2}$ or $\frac{3}{2}$.

[1] J. W. Knowles, Bull. Am. Phys. Soc. Ser. II, **2**, 16 (1957).
[2] Way, King, McGinnis, and van Lieshout, U. S. Atomic Energy Commission Report TID 5300.

S9. Neutron Resonance Parameters of Sm^{151}. R. C. BLOCK, G. G. SLAUGHTER, AND J. A. HARVEY, *Oak Ridge National Laboratory.*—The total neutron cross section of a sample of fission product samarium containing 4.8% Sm^{151} (70 year half-life) has been measured with the Oak Ridge National Laboratory fast chopper. Several resonances were observed in the energy range from 0.2 to 20 ev. Samples enriched in Sm^{147} and Sm^{149} have also been measured. After correcting for the Sm^{147} and Sm^{149} contributions to the cross section of the fission product sample, four resonances have been assigned to Sm^{151} in the energy range from 0.2 to 5 ev. The level spacing in Sm^{151} is smaller than that of Sm^{147} and Sm^{149}. Parameters for these resonances will be presented.

S10. Resonant Neutron Capture Gamma Rays from Gd and Dy.* C. A. FENSTERMACHER, T. E. SPRINGER, AND H. L. SCHULTZ, *Yale University.*—Gamma rays following neutron

TABLE I. Dysprosium capture gamma rays.

E_n(ev)	1.7	2.7	3.7	5.5
Compound nucleus	Dy^{164}	Dy^{163}	Dy^{163}	Dy^{160}
E_γ(kev)	175±10 220±10 680±20 750±20	190±10	190±10	350±15 390±15

capture in several resonances of Gd and Dy have been observed and their absolute intensities measured. A NaI scintillation spectrometer was used in conjunction with the Yale slow neutron velocity selector. The results for dysprosium along with the recently reported isotopic assignments are summarized in Table I and include some previously reported results. For gadolinium, the 2.0- and 7.8-ev resonances yielded no prominent lines in the region from 100 to 700 kev. Radiation from capture in the 2.6- and 2.8-ev levels, which were not separated, contained a 200±10 kev gamma ray which was also seen in the 6.3 ev resonance. Transitions of 200±10, 650±20, 950±30, and 1160±40 kev were observed from neutron capture in the range $E_n = 0.2$–0.3 ev.

* Research supported by the U. S. Atomic Energy Commission.

S11. Inelastic Neutron Scattering from Heavy Elements.* JULES S. LEVIN AND LAWRENCE CRANBERG, *Los Alamos Scientific Laboratory*.—A time-of-flight apparatus has been used to measure the spectra of neutrons scattered inelastically from Ta, W, and Au for incident neutron energies E_0 of 2.45, 3.40, and 6.34 Mev, and scattering angles of 30°, 90°, and 150°. Measurements were also made on Ag at the highest energy. For those scattered neutrons with 0.5 Mev $\leq E \leq \frac{1}{2}E_0$, the angular distributions were isotropic within about 10%. The energy spectra of these neutrons could be fitted with a distribution of the form $dN/dE \propto E\exp(-E/T)$. The values obtained for the nuclear temperature T in Mev are tabulated below. Estimated errors are about ±8%.

E_0(Mev)	Ag	Ta	W	Au
2.45		0.33	0.40	0.27
3.40		0.38	0.37	0.46
6.34	0.60	0.50	0.47	0.63

The data are not adequate to determine the angular distributions of the more energetic neutrons. Neutrons of energies lower than 0.5 Mev were not observed because of the decreasing sensitivity of the detector used. Cross sections for inelastic scattering were obtained by assuming the above energy distribution to hold over the entire energy range $0 \leq E \leq E_0$. This is a large extrapolation since most of the inelastically scattered neutrons were of an energy too low to be detected.

* Work performed under the auspices of the U. S. Atomic Energy Commission.

S12. Neutron Resonance Parameters for Pu^{239} and Pu^{240}.* O. D. SIMPSON AND R. G. FLUHARTY, *Phillips Petroleum Company*.—The total neutron cross sections for Pu^{239} and Pu^{240} have been measured with the Materials Testing Reactor fast chopper from 0.5 ev to 5.0 kev, using a resolution of 0.04 to 0.20 μsec/meter. Preliminary Breit-Wigner parameters have been obtained up to 100 ev for the following Pu^{240} resonances: 1.06, 20.3, 37.1, 40.4, 70, 85, 97 ev. The average Γ_n obtained from these resonances is 28±7 mv. The average level spacing from the first 8 levels was found to be 14.0 ±2.0 ev. The value of the strength function $(\bar{\Gamma}_n^0/D)$ determined for Pu^{240} is $(2.3\pm0.7)\times10^{-4}$. Several new resonances and Breit-Wigner parameters will also be presented for Pu^{239}.

* Work performed under the auspices of the U. S. Atomic Energy Commission.

S13. Problems in the Analysis of Resonances in the Slow Neutron Cross Section of U^{235}.* F. J. SHORE AND V. L. SAILOR, *Brookhaven National Laboratory*.—It has been shown[1] that in U^{235} the capture component of a resonance is symmetrical, whereas the fission component is asymmetrical in shape. In the analysis of any particular resonance the capture cross section curve can be fitted to the single-level Breit-Wigner formula by the usual procedures of "shape" analysis yield the parameters E_0, $\sigma_0\Gamma$, and Γ. The problem of obtaining the remaining parameters is complicated by the fact that a multilevel formula must be used to fit the fission cross section. A method has been devised for obtaining the ratio $\alpha = \Gamma_\gamma/\Gamma_f$ at each resonance in the energy region where shape analysis can be used. Combining this ratio with the parameters obtained from the capture cross section yields all parameters of the resonance except for the statistical weight factor g and the *sign* of the amplitudes which appear in the multilevel single channel formula. It appears possible to infer the *relative* values of these quantities for some resonances, by finding which combinations give the most reasonable fit to the data.

* Work performed under the auspices of the U. S. Atomic Energy Commission.

[1] F. J. Shore and V. L. Sailor, Bull. Am. Phys. Soc. Ser. II, 2, 70 (1957).

S14. Nonelastic Cross Sections for 8- and 11-Mev Neutrons.* W. P. BALL, M. H. MACGREGOR, AND REX BOOTH, *University of California, Livermore*.—Nonelastic cross sections were measured for 8- and 11-Mev neutrons on representative elements ranging from beryllium to bismuth by means of the sphere technique.[1] Neutrons were produced in the variable energy cyclotron by the $H^3(d,n)He^3$ reaction. Corrections have been applied for elastic energy loss, multiple scattering, finite detector size, obliquity effects, and the nonisotropy and nonisoergicity of the neutron source. A comparison will be made between the measured nonelastic cross sections and predictions of the optical model.[2]

* Work performed under the auspices of the U. S. Atomic Energy Commission.

[1] MacGregor, Ball, and Booth, Bull. Am. Phys. Soc. Ser. II, 1, 388 (1956).
[2] Bjorklund, Fernbach, and Sherman, Phys. Rev. 101, 1832 (1956).

FRIDAY EVENING AT 7:00

Shoreham, Terrace Room

(H. D. SMYTH presiding)

Banquet of the American Physical Society

After-dinner speakers to be announced.

SATURDAY MORNING AT 9:00

Shoreham, Main Ballroom

(C. G. SHULL presiding)

Ferroelectrics and Dielectrics

SA1. Double Hysteresis Loop of Pb_2 $Ca_{1-\lambda}$ TiO_3.* ETSURO SAWAGUCHI AND MELVIN L. CHARTERS, *Rutgers, The State University.*—It has been found[1] near the composition $\lambda = 0.05$, at room temperature, the ceramic sample exhibits a double hysteresis loop. If the sample is quenched from a high temperature (*ca* 200°C) to room temperature then at first the hysteresis loop is a normal ferroelectric one, however, with the passing of time it changes gradually to a double hysteresis type. When the sample is slowly cooled under a dc field the form of the hysteresis loop is asymetric and the asymmetry remains stable with respect to time. Dielectric constant and x-ray measurements have been made under various conditions. The phenomenon is difficult to explain by a forced transition with an electric field such as found in $BaTiO_3$ and $PbZrO_3$. If we assume some type of polar anisotropy with respect to the spontaneous polarization in each domain, then the phenomena may be explained.

* Sponsored in part by the Signal Corps Engineering Laboratories.
[1] Sawaguchi, Mitsuma, and Ishii, J. Phys. Soc. Japan 11, 1298 (1956).

SA2. Ferroelectricity and Structure of Tri-glycine Fluoberyllate and Isomorphs.* R. PEPINSKY, Y. OKAYA, AND F. JONA, *Pennsylvania State University.*—Matthias, Miller, and Remeika[1] discovered ferroelectricity in tri-glycine sulfate and selenate. Tri-glycine fluoberyllate is isomorphous and also ferroelectric: Curie point T_c is 75°C; $P_s = 3.2 \times 10^{-6}$ cb/cm²; coercive field is 5 kv/cm (at 20 kv/cm). Piezoelectricity disappears above T_c. At 20°C:

	$a(A)$	$b(A)$	$c(A)$	β	ρ
$T-G$ sulfate	9.64	12.75	5.90	111°	1.656_4
$T-G$ selenate	9.54	12.92	5.86	110°	1.845_2
$T-G$ fluoberyllate	9.59	12.75	5.70	112°	1.631_4

Space group: $P2_1$, below T_c; $P2_1/m$ above. X-ray intensities from the sulfate are essentially unaltered above and below T_c; the fluoberyllate shows differences; the selenate shows stacking disorder along a, immediately above T_c. The structure above T_c: one glycine and the inorganic anion are on a mirror plane: two glycines are mirrored across the plane; H bonds maintain the structure. The mirror symmetry, chiefly of H's, disappears below T_c, producing polarization along b. Optically active amino acids only, and acid-unstable inorganic anions, cannot form isomorphous crystals.

* Research supported by Air Force Office of Scientific Research and Signal Corps Engineering Laboratories.
[1] Matthias, Miller, and Remeika, Phys. Rev. 104, 849 (1956).

SA3. X-Ray and Neutron Structure Analysis of Ferroelectric Rhombohedral $Pb(Zr_{0.75}, Ti_{0.25})O_3$ at Room Temperature.* F. UNTERLEITNER, G. SHIRANE, F. JONA, AND R. PEPINSKY, *The Pennsylvania State University.*—The solid solution $Pb(Zr_{0.75}, Ti_{0.25})O_3$ is ferroelectric and rhombohedral at room temperature,[1] and is cubic (perovskite) at higher temperature. No ferroelectric rhombohedral structure had been completely established heretofore. A powder x-ray analysis established heavy atom positions in this rhombohedral phase; oxygen positions were determined from a neutron powder pattern. The space group is $R3m$, with cell constants $a = 4.11$ A, $\alpha = 89°41'$. Atomic coordinates are: Pb at (δ,δ,δ), with $\delta = 0.575$; (Zr,Ti) at $(\epsilon,\epsilon,\epsilon)$, with $\epsilon = 0.040$; 0 at $(\gamma,0,0)$, $(0,\gamma 0)$, $(0,0,\gamma)$ with $\gamma = 0.520$. The oxygen octahedra surrounding the (Zr,Ti) atoms are only slightly distorted, and atomic displacements are of the same order as in tetragonal ferroelectric $PbTiO_3$.[2]

* Research supported by Air Force Office of Scientific Research, Signal Corps Engineering Laboratories, and U. S. Atomic Energy Commission.
[1] E. Sawaguchi, J. Phys. Soc. Japan 8, 615 (1953).
[2] Shirane, Pepinsky, and Frazer, Acta Cryst. 9, 131 (1956).

SA4. Ferroelectricity in Thiourea. GEORGE J. GOLDSMITH, *RCA Labs.*—Thiourea[1] ($C(NH_2)_2S$) is the only known ferroelectric material which is non-ionic. The ferroelectric axis is the orthorhombic 010. It has a Curie temperature of about −104°C, spontaneous polarization at −110°C of 3 microcoulombs/cm² and a 60-cycle coercive field at that temperature of about 500 v/cm. The transition is first order in all samples observed as evidenced by the appearance of double hysteresis loops[2] and by a distinct discontinuity in the P_s *vs* T relation. The Curie temperature has a strong field dependence. The low-field dielectric constant as a function of temperature displays three anomalies, two of which occur at temperatures above the Curie point. In the vicinity of the lower of these two anomalies there is evidence of a second ferroelectric phase showing a very small P_s and E_c. The room temperature dielectric constant is 100 along the ferroelectric direction.

[1] A. L. Solomon, Phys. Rev. 104, 1191 (1956).
[2] W. J. Merz, Phys. Rev. 91, 513 (1953).

SA5. Dielectric Properties of Cadmium Niobate. A. DE-BRETTEVILLE, JR., AND F. A. HALDEN,* *Signal Corps Engineering Laboratories.*—Ceramic, not pressed cadmium niobate of 6.0 g/cc density (theoretical 6.28 g/cc) was examined at 1 kc and 100 v/cm field strength with a capacitance bridge. An unreported minor peak in the dielectric constant was found at −70°C, 10°C above the major peak at −80°C. This minor dielectric peak was also found with dry pressed and fired ceramics and melt-gradient grown crystals. A Bruel and Kjoer harmonic analyzer was employed to obtain polarization components at 60 cps and 10 kv/cm from room temperature to −170°C. An equation was developed for the polarization as a function of odd powers of the field strength. Coefficients of this equation contain the amplitudes of the fundamental, third, and fifth harmonics of the polarization, obtained at each temperature from the harmonic analyzer. The harmonic contents increase rapidly from −70°C to −90°C and then gradually decrease. By inserting these harmonic amplitudes in the polarization *vs* field strength equation, one obtains the lossless hysteresis curve for any given temperature. A third harmonic of polarization, amounting to 1% of the fundamental at room temperature was found to exist far above the Curie temperature.

* Presently employed by Stanford Research Institute.

Invited Papers

SA6. Semiconductor Research Leading to the Point Contact Transistor. J. BARDEEN, *University of Illinois.* (40 min.)

SA7. Physics of Semiconductor Surfaces. W. H. BRATTAIN, *Bell Telephone Laboratories.* (40 min.)

SA8. Amplification of Microwaves by Atomic Processes. C. H. TOWNES, *Columbia University.* (40 min.)

SATURDAY MORNING AT 9:30

Shoreham, West Ballroom

(M. M. BLOCK presiding)

Heavy Mesons and Hyperons I

T1. Observation of the Reaction $\pi^+ + p^+ \rightarrow \Sigma^+ + K^+$ at 1.1 Bev.* J. C. VANDER VELDE, J. L. BROWN, D. A. GLASER, D. I. MEYER, AND M. L. PERL, *University of Michigan*, AND J. W. CRONIN, S. DE BENEDETTI,† AND R. COOL, *Brookhaven National Laboratory*.—The University of Michigan 12-in. propane bubble chamber was exposed to a magnetically focused and analyzed beam of positive particles from the Cosmotron. The proton to pion ratio in the beam was 1.65 and approximately 230 000 feet of pion track was photographed in an effort to detect the reaction $\pi^+ + p^+ \rightarrow \Sigma^+ + K^+$ which would occur in a pure $T = \frac{3}{2}$ state. A preliminary analysis of three-fourths of the pictures showed the following results. Nine events were seen in which either the Σ^+ or the K^+ showed a definite decrease of bubble density at decay and which satisfied the requirements of kinematics and bubble density for the above reaction with free protons. In three of these cases both particles decayed in the chamber, the K^+ coming to rest and providing an additional check on the beam momentum. Data from the completed experiment pertaining to cross section, lifetime, and angular distributions will be presented.

* Work supported in part by the U. S. Atomic Energy Commission.
† Permanent address: Carnegie Institute of Technology.

T2. Properties of Λ^0 and θ^0 Particles Produced by 1.1-Bev π^- Mesons Where the Decay of Only One Neutral V is Observed.* C. GRAVES, J. BROWN, D. GLASER, AND M. PERL, *University of Michigan*.—The properties of Λ^0 and θ^0 particles are being studied with the Michigan 12-inch propane bubble chamber, using a momentum-analyzed beam of 1.1-Bev π^- mesons from the Brookhaven Cosmotron. The results of the analysis of 22 000 pictures for the reaction $\pi^- + p \rightarrow \Sigma^- + K^+$ and the reactions $\pi^- + p \rightarrow \Sigma^0 + \theta^0$ or $\pi^- + p \rightarrow \Lambda^0 + \theta^0$ have been reported previously.[1] However, for the latter two reactions only those cases were presented where the decay of both unstable particles was observed. A similar analysis of the latter reactions where the decay of only one of the neutral unstable particles is observed has also been made. Results concerning angular distributions of production and decay, angular correlations, lifetimes, possibility of neutral decay modes, parity doublets, and conservation of parity will be presented.

* Work supported in part by the U. S. Atomic Energy Commission.
[1] Brown, Glaser, and Perl, Bull. Am. Phys. Soc. Ser. II, **2**, 19 (1957).

T3. Production of K^+ Mesons by 3-Bev Protons on Hydrogen.* G. HARRIS, J. OREAR, S. TAYLOR, AND P. BAUMEL, *Columbia University*.—Liquid hydrogen, lithium, and copper targets were exposed to the Cosmotron 3-Bev external beam. Positive particles of 275 Mev/c leaving the target at 0° in the laboratory system were magnetically analyzed and detected in nuclear emulsion stacks. Preliminary laboratory differential cross sections for K^+ are $d^2\sigma/d\omega dE = (5 \pm 2)$ and $(3.2 \pm 0.7) \times 10^{-28}$ cm²/sterad/Mev per nucleon for hydrogen and copper respectively. The π^+/K^+ ratios are (700 ± 300) for hydrogen and (570 ± 120) for copper. All above values have been corrected for decay in flight. The K^+ cross section from hydrogen has been corrected for a $(10 \pm 6)\%$ background which is based on 3 K's found in an empty target exposure. Such a low background was achieved by using 14.8 inches of liquid hydrogen in a Styrofoam target with $\frac{1}{4}$ mil Mylar windows of 6 inches diameter. Relative to their total cross sections, copper is (1.35 ± 0.6) times more effective than hydrogen in producing K^+ (at 0° and 275 Mev/c), while both copper and hydrogen are equally effective in producing π^+. All errors correspond to one standard deviation. Additional scanning is in progress.

* Research supported by the U. S. Atomic Energy Commission and the National Science Foundation.

T4. Production of Heavy Unstable Particles by 1.3-Bev Kinetic Energy π^- Mesons in a Propane Bubble Chamber.* F. R. EISLER, R. PLANO, N. P. SAMIOS, AND J. STEINBERGER, *Columbia University*, AND M. SCHWARTZ, *Brookhaven National Laboratory*.—This is a continuation of a previous study[1] of the production of heavy unstable particles but with a larger propane bubble chamber and the addition of a magnetic field. The chamber is cylindrical in shape, 12 in. in diameter and 8 in. in depth. The magnetic field strength is 13.4 K gauss. A 1.3-Bev kinetic energy π^- beam was introduced into the chamber. The reactions studied were (a) $\pi^- + p \rightarrow \Sigma^0 + \theta^0$; (b) $\pi^- + p \rightarrow \Lambda^0 + \theta^0$; (c) $\pi^- + p \rightarrow \Sigma^- + K^+$. Approximately 18 000 pictures were taken and 250 hydrogen events obtained. The angular distributions in production and the angular correlations in decay will be presented.

* This research was supported in part by the U. S. Atomic Energy Commission and the Office of Naval Research.
[1] Budde, Chretien, Leitner, Samios, Schwartz, and Steinberger, Phys. Rev. **103**, 1827 (1956).

T5. Calculations Concerning the Z Dependence of Unstable Particle Production.* GEORGE T. REYNOLDS AND S. B. TREIMAN, *Princeton University*.—A simple one-dimensional calculation of the Z dependence of unstable particle production in nuclei will be described. The Z dependence for direct production by a nucleon has been compared to that expected for the production of the unstable particle by the mechanism of the nucleon producing a π meson which then produces the unstable particle ("cascade production"). The results depend upon the interaction cross section assumed for the unstable particle emerging from the nucleus. For direct nucleon production the ratio of the cross sections per nucleon in carbon and lead is ~2:1 if the unstable particle is weakly absorbed; for cascade production the corresponding ratio is ~1.3:1. For cascade production with the unstable particle strongly absorbed the ratio of cross sections per nucleon in carbon and lead is ~3:1. These considerations form the basis of the experiment described in the following paper.

* Supported by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.

T6. Unstable Particle Production in Carbon, Iron, and Lead by π^- Mesons and Protons.* T. BOWEN, G. E. MASEK, GEORGE T. REYNOLDS, L. SARTORI, G. TAGLIAFERRI, AND A. WERBROUCK, *Princeton University*, AND W. H. MOORE, *Brookhaven National Laboratory*.—Approximately three hundred examples of unstable particle production by 1.6-Bev π^- mesons and 2.8-Bev protons have been obtained by operating a 36-in. multiplate cloud chamber in the π^- and blowup proton beam of the Brookhaven Cosmotron. The plate assemblies used were successively 15 iron plates; 7 lead plates; a mixed assembly containing 7 carbon and 4 lead plates. All plates were $\frac{1}{4}$ in. thick. Relative numbers of Λ^0's, θ^0's, and V^2's for production in C, Fe, and Pb will be presented. Relative cross sections for production will be discussed as a function of atomic number and compared with the results of the previous paper.

* Supported by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.

T7. Production of Strange Particles in Proton-Proton Collisions at 1.95-Bev Incident Energy.* E. C. FOWLER, H. L. KRAYBILL, AND R. M. LEA,† *Yale University.*—The production of heavy mesons and hyperons in free proton-proton collisions was studied by exposing the hydrogen filled Brookhaven diffusion cloud chamber to the external proton beam at the cosmotron. A proton flux of about 500 protons per picture was made possible without a general loss of sensitivity by confining the incident protons to a narrow pencil by collimation and strong focusing. This pencil-beam was passed through the center of the chamber's sensitive region about twice per minute. At 1.95-Bev kinetic energy 8500 photographs were obtained, corresponding to a path length in H_2 of about 1.3×10^5 g/cm². One neutral V particle has been identified as produced in the pencil. We are attempting to determine whether any of the few additional V's originated in the pencil. These events and a calculation of efficiency for observation will be discussed. We wish to acknowledge the generous help extended by the Brookhaven Laboratory staff; especially Dr. Ralph P. Shutt and other members of the cloud chamber group and also Dr. Rodney L. Cool.

* This work was supported in part by the U. S. Atomic Energy Commission.
† General Electric Research Fellow, 1956–1957.

T8. Production of V Particles by 3-Bev Protons.* R. L. COOL, T. W. MORRIS, R. R. RAU, A. M. THORNDIKE, AND W. L. WHITTEMORE, *Brookhaven National Laboratory.*—For comparison with data on the production of hyperons and K mesons in π-p collisions an experiment was performed to investigate production in p-p collisions directly. The external 3-Bev beam of the Cosmotron was collimated and focused to about 1 cm². Using approximately 500 protons per pulse through a diffusion cloud chamber, $\sim2\times10^5$ g/cm³ of proton traversal of hydrogen has been recorded. While the efficiency for detecting V events is considerably less than one, the small number observed from hydrogen indicates that the cross section for production of V events in p-p collisions is considerably less than in π-p collisions at roughly the same available energy in the center-of-mass system. Similarly, the p-p cross section is smaller than that deduced for p-nucleon collisions in a heavy nucleus. Berley and Collins[1] have reached the same conclusion using a less direct method.

* Work performed under the auspices of the U. S. Atomic Energy Commission.
[1] David Berley and George B. Collins, Bull. Am. Phys. Soc. Ser. II, 1, 320 (1956).

T9. Heavy Fragment Emission in Nuclear Emulsions Induced by 0.4, 2, and 3-Bev Protons.* E. BAKER AND S. KATCOFF, *Brookhaven National Laboratory.*—Ilford D-1 (200 μ) emulsions were irradiated in the Brookhaven Cosmotron with 0.4-, 2.0-, and 3.0-Bev protons, and the larger stars, those produced only in the AgBr, were studied. Under the development conditions used the D-1 plates were sensitive to protons up to ~5 Mev, to alpha particles up to ~50 Mev, and to heavier fragments. At 0.4 Bev the number of fragments heavier than alpha particles per star, in addition to the recoil, was ~0.1; and at 2.0 and 3.0 Bev this value rose to ~1.0. At 2.0 and 3.0 Bev an appreciable number of events showed three and four heavy fragments per star. Preliminary data will be presented on the variation of the multiplicity of heavy fragments per star with the energy of the incident protons. Comparisons will be made with previous radio-chemical data and cosmic-ray data. Identification of the fragments was made by visual comparison with known proton, deuteron, and alpha tracks from a cyclotron and with fission tracks from uranium. Where feasible, gap counting was done to confirm the method of identification.

* Research performed under the auspices of the U. S. Atomic Energy Commission.

T10. K^- Interaction in Hydrogen.* P. FALK-VAIRANT,† L. W. ALVAREZ, HUGH BRADNER, J. D. COW, A. H. ROSENFELD, F. T. SOLMITZ, AND R. D. TRIPP, *University of California, Berkeley.*—A report on the first 137 K^- interactions seen in the Berkeley 10-in. hydrogen bubble chamber has already been given.[1] The experiment is continuing and the number of observed hyperons has been doubled. From K^-+P interactions at rest we have a total of $106\Sigma^-$, $59\Sigma^+$, 6 ambiguous $\Sigma^\pm$; and 70 visible decays of Σ^0's and Λ's. All the qualitative conclusions suggested by the earlier events are now strengthened with the following important exception. The angular distribution of the decay products of the first 65 charged Σ's showed some anisotropy, suggesting that the Σ has a spin greater than $\frac{1}{2}$. Preliminary analysis of the present angular distribution which now includes 155 decays shows that it has become consistent with isotropy.

* This work was performed under the auspices of the U. S. Atomic Energy Commission.
† On leave from CEA, Saclay, France.
[1] Solmitz, Alvarez, Bradner, Falk, Gow, Rosenfeld, and Tripp, Bull. Am. Phys. Soc. Ser. II, 1, 385 (1956); also University of California Radiation Laboratory unpublished report 3583 and Nuovo cimento (to be published).

T11. Total Cross Section for 190-Mev K^+ Mesons on Nuclei. LEROY T. KERTH, THADDEUS F. KYCIA, AND LUD VAN ROSSUM, *University of California, Berkeley.**—The attenuation cross sections of C, Al, Cu, Ag, and Pb, for K^+ mesons at 190 ± 30 Mev have been measured. K^+ mesons were identified in a momentum-analyzed beam by the velocity as determined by two Čerenkov counters and pulse height in two scintillation counters. The K^+ mesons then entered the various targets. Two scintillation counters detected those K^+ particles leaving the target within a cone of 22° and 41° half-angle. The cross sections are given in Table I. The errors are statistical standard deviations. A good fit to the data is obtained by assuming a K^+-nucleon cross section of about 10 mb, or a K^+-proton cross section of 20 mb and a K^+-neutron cross section of 0.

TABLE I. Cross sections in millibarns for the various targets.

Geometry	C	Al	Cu	Ag	Pb
22°	96 ± 9	208 ± 15	505 ± 30	578 ± 40	1081 ± 90
41°	83 ± 8	148 ± 15	384 ± 25	451 ± 35	749 ± 70

* This work was done under the auspices of the U. S. Atomic Energy Commission.

T12. Interactions in Flight and Decays of Negative K Mesons.* F. C. GILBERT, C. E. VIOLET, AND R. S. WHITE, *University of California, Livermore.*—Negative K mesons from the Bevatron were stopped in several nuclear emulsion stacks. 103 interactions-in-flight and 17 decays-in-flight have been found in following 30 meters of negative K-particle track. The energy at the point of interaction varied from 16 Mev to 150 Mev. The masses of the interacting particles were determined by multiple scattering and ionization measurements. The mean free path is 30 ± 3 cm. The 17 decays give a mean life of $(1.1\pm0.3)\times10^{-8}$ second. 10 possible (K^-,p) scatters give an elastic scattering cross section on hydrogen of 104 ± 33 millibarns. The prong distributions and nature of the negative K-particle interactions will be discussed.

* Work was performed under the auspices of the U. S. Atomic Energy Commission.

T13. Interaction Properties of Positive K Mesons.* J. LANNUTTI, W. W. CHUPP, G. GOLDHABER, AND S. GOLDHABER, *University of California, Berkeley.*—We have investigated the interactions of positive K mesons in nuclear emulsions in the energy interval 100 to 200 Mev.[1] By observing 90 meters of K-meson path length we have determined the following quantities: (a) The mean free path for incoherent scattering, i.e., charge-exchange and inelastic scattering ($\Delta E/E$

>10%), is 76(+9, −6) cm; (b) The ratio of charge-exchange to inelastic scattering is 0.25±0.05; (c) The K-hydrogen cross section is 28(+15, −10) mb. In addition we have obtained the elastic differential-scattering cross section for angles greater than 2° in the two energy intervals 40 to 100 Mev (18 meters of track followed) and 100 to 200 Mev (90 meters of track followed). The 40- to 100-Mev data have been compared with an optical model calculation by G. Igo, G. Ravenhall, and J. Tiemann, of Stanford University, and gives very good agreement with a repulsive real potential of about +12 Mev. A similar calculation with an attractive real potential of the same magnitude gives destructive interference with Coulomb scattering, and lies below our data in the 10° to 15° region by factors of 5 to 10.[3]

[*] This work was done under the auspices of the U. S. Atomic Energy Commission.
[1] Part of our stack is under study by G. Quareni and G. Puppi at Bologna. Our combined data will be presented later.
[3] Groups at Padua and Bologna have arrived at similar conclusions (private communications).

T14. Analysis of Negative K-Meson Stars in Emulsion. N. SEEMAN, R. G. GLASSER, AND G. A. SNOW, *Naval Research Laboratory.*—Two stacks of G.5 emulsion have been exposed to K^- meson beams of the Berkeley Bevatron. 73.6 cm³ of emulsion in the first stack were area scanned and 108 K^- stars were found. Systematic following of the prongs from these K^- stars yielded the following numbers: 29 charged pions, 17 hyperfragments, and 25 charged hyperons. Of the latter, there were $4\Sigma^+\to p+\pi^0$ decays at rest, $3\Sigma^+\to\pi^++n$ decays at rest, $2\Sigma^+\to p+\pi^0$ decays in flight, $6\Sigma^+\to\pi^++n$ decays in flight (two are identified as positive), and 6 identified Σ^- stoppings. From the $6\Sigma^+\to p+\pi^0$ decays the mean life of the Σ^+ hyperon is $1.38(+1.39, -0.63)\times10^{-10}$ sec. The average lifetime of the mixture of Σ^+ hyperons which decay in flight into π^++n is $0.36(+0.41, -0.13)\times10^{-10}$ sec. The angle ($\theta_{\Sigma\pi}$) between the Σ and the pion from its decay in the Σ rest system is greater than 90° in 9 out of 15 cases. In 8 out of 15 cases $|\cos\theta_{\Sigma\pi}|\geq0.5$. Additional results will be presented from the second stack, which was exposed to a separated K^+ beam.

SATURDAY MORNING AT 9:30

Sheraton-Park, Continental Room

(K. T. BAINBRIDGE presiding)

Atomic Masses; General Nuclear Physics

TA1. Atomic Masses from Phosphorus through Manganese.* CLAYTON F. GIESE† AND JAY L. BENSON, *University of Minnesota.*—The atomic masses of all stable isotopes in the range $15\leq Z\leq25$ have been measured using the Minnesota 16-in. precision mass spectrometer.[1] The masses are considered to have an accuracy of roughly 1 part in 10 000 000. Comparisons are made with previous results from Minnesota and from other mass spectrometric laboratories. Certain mass ratios may be compared with those obtained by the methods of microwave spectroscopy. Finally, the present masses are compared with recent determinations from nuclear reaction Q values.

[*] Research supported by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.
† National Science Foundation Predoctoral Fellow 1954–1957. Now at the University of Chicago.
[1] Quisenberry, Scolman, and Nier, Phys. Rev. **102**, 1071 (1956).

TA2. Measurements of Some Light Masses with the Mass Synchrometer.* LINCOLN G. SMITH, *Brookhaven National Laboratory.*—The mass synchrometer[1] has been employed to measure with high precision the doublets $C_3D_8-C_4D_2$ and CD_4-D_2O and thus to obtain values of the masses of C^{12} and D by a method which completely avoids possible systematic errors resulting from dissociation ions. The "best values" for the ten doublets at mass 20 (including CD_4-D_2O) involving the ions A^{40++}, Ne^{20+}, D_2O^+, ND_3^+, and CD_4^+ (all of which are parent ions) were obtained by weighted least-squares adjustment of the ten measured values. Hence, the following mass defects in μMU have been obtained: $D=14\,739.97\pm0.03$; $C^{12}=3814.58\pm0.11$; $N^{14}=7524.49\pm0.18$; $Ne^{20}=-1204.49\pm0.13$; $A^{40}=-24\,903.58\pm0.44$. Each doublet was measured between 20 and 100 times under various conditions over a period of several months with half-width resolution of about 20 000. Errors are estimated probable errors of the means. A discussion of precision and special precautions taken will be presented.

[*] Work performed under the auspices of the U. S. Atomic Energy Commission.
[1] Lincoln G. Smith and C. C. Damm, Rev. Sci. Instr. **27**, 618 (1956).

TA3. Revised Atomic Masses of H^1, C^{12}, and S^{32}.† K. S. QUISENBERRY, C. F. GIESE,* AND J. L. BENSON, *University of Minnesota.*—The Minnesota 16-in. precision mass spectrometer has been used to redetermine the atomic masses of H^1, C^{12}, and S^{32} relative to the O^{16} standard. The techniques of instrument calibration and operation have been improved since the previous secondary standard masses were reported.[1] Instrument dispersion is tested by measurement of mass "doublets" one hydrogen mass wide. Results of 24 such measurements over a six-month interval give $H^1=1.0081443\pm13$, suggesting the instrument dispersion is correct to about 2 ppm. The error given does not include the resistance calibration uncertainty which is estimated to be no more than 10 ppm. Hence this larger error is included in the error quoted on all doublet results. The C^{12} mass is now determined using the doublet $\frac{1}{4}C_4H_4O-H_2O_2$ suggested by Kettner.[2] New doublet results used to obtain masses are: $CH_4-O=36.3961\pm5$, $\frac{1}{4}C_4H_4O-H_2O_2=7.6311\pm8$, and $O_2-S=17.7623\pm11$ $m\mu$. Resultant secondary masses are: $H^1=1.0081451\pm2$, $C^{12}=12.0038156\pm4$, and $S^{32}=31.9822377\pm11$. These masses will be compared with those presented previously together with discussion relating to possible sources of error.

† Research supported by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.
* National Science Foundation Predoctoral Fellow 1954–1957. Now at the University of Chicago.
[1] Quisenberry, Scolman, and Nier, Phys. Rev. **102**, 1071 (1956).
[2] M. E. Kettner, Phys. Rev. **102**, 1065 (1956).

TA4. A Revised Semiempirical Atomic Mass Formula. A. G. W. CAMERON, *Chalk River Laboratories.*—In older semiempirical atomic mass formulas the Coulomb energy includes an adjustable nuclear radius, which has been found too large compared to modern determinations of nuclear charge radii. J. Mathews (unpublished) has shown that a smaller radius is obtained when the Coulomb energy is computed for a trapezoidal radial charge distribution. In the present work, motivated by a desire to obtain nuclear reaction energies both near and far from the valley of beta stability, a trapezoidal radial model was used for the nucleus, with skin thickness and radius fixed

to agree with the Stanford electron scattering results. Coulomb and Coulomb exchange energies were computed for this model. Symmetry energy contributions to the surface and volume energies were least-squares adjusted to fit the valley of beta stability. The surface and volume energies were least-squares adjusted to fit the masses of 89 odd-odd nuclei evenly spaced in mass number. This procedure gave a good fit to the trend of masses in the range $25 < A < 250$. The differences between the Wapstra-Huizenga experimental masses and the semi-empirical formula were analyzed to determine empirical shell and pairing corrections as functions of the proton and neutron numbers. A table of masses is being calculated and will be published together with particle-binding and beta-decay energies in a Chalk River report.

TA5. Neutron Binding Energy Systematics in the Region $N=82$ to 126.* W. H. JOHNSON, JR., AND V. B. BHANOT,† *University of Minnesota.*—A 6-in. double-focusing mass spectrometer, used to measure a number of previously reported mass differences,[1] has been employed to determine 32 mass differences between neighboring stable isotopes for each even-Z element in the region $Z=64$ to 82. The standard error associated with the present measurements is about ± 0.075 $m\mu$. Wherever possible, the present mass differences were compared with similar mass differences determined from nuclear reaction Q values. The agreement, in general, is excellent. Neutron separation energies for 32 nuclei in this region were calculated from the experimental results. Neutron pairing energies for 20 nuclei in the region $N=82$ to 126 have been calculated from neutron separation energies. These data show the previously reported maximum in the neutron pairing energies near $N=90$[1] together with another maximum near $N=116$. Both maxima in neutron pairing energies correspond to regions in which other nuclear properties also show discontinuous behavior.

* This research was supported by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.
† On study leave from Muslim University, Aligarh.
[1] W. H. Johnson, Jr., and A. O. Nier, Phys. Rev. **105**, 1014 (1957).

TA6. Numerical Relationships for the Masses of the Elementary Particles when Expressed in Terms of the Electron Mass. ENOS E. WITMER, *University of Pennsylvania.*—The writer[1] has pointed out that interesting numerical relationships exist when *nuclear* masses are expressed in terms of the rest mass of the electron. This naturally suggests that similar relationships should exist for the masses of the elementary particles. Except for the electron, proton, and neutron, however, the latter masses are not known accurately enough to test the aforesaid relationships. It is true, however, that the masses of the elementary particles including hyperons are approximately integral multiples of α^{-1} or 137, except for the μ meson, proton, and neutron. This relationship is only approximate. Also the mass of the μ meson is very nearly $(\frac{1}{2})\alpha^{-1}$. The masses of the proton and neutron are about $13.41\alpha^{-1}$, so that this multiplying factor is in the neighborhood of 27/2, but the relationship is not very accurate. The mass of the K mesons is very nearly 7/2 times the mass of the $\pi^{\pm}$ mesons, which reminds one of a previous[1] relationship.

[1] E. E. Witmer, Phys. Rev. **95**, 667 (1954); **95**, 610 (1954).

TA7. Velocity Selection by Means of a Single Čerenkov Counter.* P. E. CONDON, H. GURSKY, AND GEORGE T. REYNOLDS, *Princeton University.*—A Čerenkov counter containing toluene has been constructed in such a way that only the light emerging from the material is detected by photomultipliers. The container is rectangular in shape, 6 in. vertical depth with a cross-sectional area of 9×18 in. A particle of velocity greater than 0.70 c will emit light in a cone whose angle depends on the velocity. Thus a particle incident normally to the cross section of the counter with a velocity greater than 0.89 c will emit light in a cone whose angle is such that complete internal reflection occurs. Thus in principle detection by external photomultipliers is limited to particles of velocity between 0.70 c and 0.89 c. The device has been tested by means of cosmic ray μ mesons defined by a Geiger counter telescope, and range in lead. Results show that at the voltage biases chosen, the device is greater than 50% efficient under circumstances where it gives false counts in less than a few percent of the cases. Corrections for showers, knockons, and detection voltage biases will be discussed.

* Supported by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.

TA8. A Gas Čerenkov Counter for Use as a Proton Threshold Detector.* R. B. SCHWARTZ, H. PALEVSKY, D. J. HUGHES, AND J. D. FOX, *Brookhaven National Laboratory.*—A gas-filled Čerenkov counter has been constructed for use as a threshold detector for protons in the Bev energy range. Constructed of cold-rolled steel to withstand pressures of 100 atmos, the counter is 90 cm long and has an entrance aperture 10 cm in diameter. The optical system consists of a front-surfaced spherical mirror, which focuses the Čerenkov light through a quartz window onto a wavelength shifter and a type 6810 photomultiplier. In preliminary tests at the Brookhaven Cosmotron, $1\frac{1}{2}$ v pulses were obtained from the plate of the 6810 with a pressure of 57 atmos of CO_2 in the counter, the pulse size decreasing with decreasing pressure. A clearly defined threshold was observed at 50 atmos, the theoretical threshold for Cosmotron protons. At pressures above 52 atmos, the detection efficiency was approximately 100%.

* Work performed under contract with the U. S. Atomic Energy Commission.

TA9. On the Production of Experimental Quantities of Isomers. JOHN A. VREELAND, *Westinghouse Commercial Atomic Power Activities.*—The availability of large (20 g) quantities of separated isotopes and high $[10^{14}(n/\text{cm}^2\ \text{sec})]$ flux reactors can be combined to produce macroscopic quantities of isomeric nuclei which are relatively unadulterated by other elements. Modern radiochemistry is sufficient in most cases to limit the end product to a pair or set of genetically related isomers. In the event that radiochemical techniques do not apply to a particular element, electromagnetic separation can probably be effected. With such large quantities of isomeric nuclei, one could investigate the excited state with precisely the same techniques now used on the ground state. The determination of such quantities as angular momentum, magnetic moment, isotope shift, etc., could be made by the same spectroscopic techniques now used on radioactive elements. Various cross sections, angular distributions, etc., could similarly be determined by relatively standard techniques. In addition to acquiring information such as charge distribution, nuclear radius, etc., which is otherwise unavailable; one could check the determination of nuclear parameters by techniques used in excited states against the results of ground state techniques. Particular isomers which appear to possess especially promising possibilities are discussed as are limitations on feasibility in general.

TA10. Subcritical *vs* Supercritical Reactors. L. B. BORST, *New York University.*—Supercritical reactors commonly considered are operated within the restricted interval of delayed neutron control. When prompt criticality is exceeded, their kinetic behavior becomes extremely rapid and usually results in destruction of the physical system. Subcritical systems bear the same relation to supercritical systems that amplifiers bear to oscillators. The ratio of output to input is rigidly fixed. As such, they are immune to excursions. Technical solutions will be proposed for subcritical research devices and power plants.

TA11. Subcritical Reactor Amplifier. P. MICHAEL AND L. B. BORST, *New York University.*—A two-group transport approximation will be presented for a subcritical reactor amplifier appropriate to a high-flux reactor system.

TA12. Velocity Loss by Carbon Ions.* T. H. BRAID† AND R. W. DETENBECK,‡ *Princeton University.*—18-Mev protons were scattered from very thin targets of polystyrene. A beam of C^{12} ions of $v=7.7$ and 6.9×10^8 cm/sec was defined by counting coincidences between protons scattered backwards and the recoiling nuclei at 30°. The time-of-flight spectrum of the ions over a 1-m path was measured by a time sorter.[1] Thin films of polystyrene and evaporated aluminum and gold were interposed 10 cm from the target. The increase in flight time gave dv/dx for the particular velocity. At $v=7.7\times10^8$ cm/sec dv/dx is 10, 4.2, and 1.3×10^7 cm/sec/μg for polystyrene, aluminum, and gold, respectively. The principal source of error is in the measurement of absorber thickness.

* Supported by the U. S. Atomic Energy Commission and the Higgins Scientific Trust Fund.
† Now at Argonne National Laboratory.
‡ National Science Foundation Predoctoral Fellow during 1955–1956.
[1] T. H. Braid and R. W. Detenbeck, Phys. Rev. **99**, 663 (1955).

TA13. Nuclear Size by Potential Scattering Cross Section.* D. J. HUGHES, K. K. SETH, AND R. L. ZIMMERMAN, *Brookhaven National Laboratory.*—The potential scattering cross section, σ_p, is given by $4\pi(R')^2$, with R' related to the nuclear radius R in terms of the parameters of the nuclear potential. The potential scattering has been determined by two methods for a number of elements whose atomic weights range between 70 and 238. In the energy range where resonances are well resolved and their parameters known from separate measurements, σ_p was determined by subtracting the contributions of resonances, choosing energy regions where such contributions are small. The second method depends on averaging over resonances in the kilovolt region, determining average transmissions for different sample thicknesses. The slope of the transmission curve, at thicknesses for which self-protection and interference dip effects are small, gives σ_p directly. The results of the two methods are consistent and agree in general with predictions of recent calculations based on a potential well with a diffuse boundary and the "cloudy crystal ball" model of the nucleus. A value of $R=1.35\,A^{\frac{1}{3}}\times10^{-13}$ cm is determined by the fit of the theory to the experimental data without a strong dependence on the other nuclear potential parameters used in the calculations.

* Work performed under contract with the U. S. Atomic Energy Commission.

SATURDAY MORNING AT 9:30

NBS, East Building

(R. V. POUND presiding)

Magnetic Resonance

U1. NMR of B^{11} in Soda-Boric Oxide Glasses.* A. H. SILVER, J. G. O'KEEFE, AND P. J. BRAY, *Brown University.*—The nuclear magnetic resonance of B^{11} has been studied in soda-boric oxide glass as a function of Na_2O concentration. The spectrum consists of a narrow line superimposed on a broad asymmetric line due to the $m=\frac{1}{2}\rightarrow-\frac{1}{2}$ transition distorted by second-order quadrupole interaction. The relative intensity of the narrow line increases from zero in 100% B_2O_3[1] and the intensity of the broad line decreases with increasing Na_2O. The width of the broad resonance, and therefore the quadrupole coupling constant of the boron nuclei contributing to it does not vary measureably with composition. The presence of excess oxygen from the Na_2O changes the coordination number of some boron atoms from 3 to 4 reducing the quadrupole interaction in these cases and producing the narrow line. These results are in agreement with x-ray studies of Biscoe and Warren.[2]

* Research supported by the U. S. Atomic Energy Commission and the National Science Foundation.
[1] A. H. Silver and P. J. Bray, Bull. Am. Phys. Soc. Ser. II, **1**, 324 (1956).
[2] J. Biscoe and B. E. Warren, J. Am. Ceram. Soc. **21**, 287 (1938).

U2. Nuclear Quadrupole Coupling Constant of Na^{23} in $NaNO_2$.* JOHN F. HON AND P. J. BRAY, *Brown University.*—Using a recording spectrometer of the Pound-Watkins type the nuclear magnetic resonance of Na^{23} was observed in a pressed powder sample of $NaNO_2$. From the shape of the $m=-\frac{1}{2}\rightarrow\frac{1}{2}$ transition the quadrupole coupling constant was found to be 1.09 ± 0.07 Mcps assuming the asymmetry parameter η to be negligible. The coupling constant can be written as λeqQ where λ is a multiplicative factor expressing the effect of the polarization[1] and mechanical squeezing[2] of the ion core. The electric field gradient component q is being computed using an ionic model for the known structure of $NaNO_2$[3,4] in order to estimate λ. The results of this computation will be presented.

* This work was supported by the U. S. Atomic Energy Commission.
[1] Foley, Sternheimer, and Tycko, Phys. Rev. **93**, 734 (1954).
[2] N. Bloembergen, "Defects in crystalline solids," Report of 1954 Bristol Conference.
[3] G. E. Zeigler, Phys. Rev. **38**, 1040 (1931).
[4] G. B. Carpenter, Acta Cryst. **5**, 132 (1952).

U3. Nuclear Magnetic Resonance Spectrum of Chrysoberyl.* J. H. HOCKENBERRY, JR., L. C. BROWN, and DUDLEY WILLIAMS, *The Ohio State University.*—The quadrupole splitting of the Al^{27} magnetic resonance absorption lines in a single crystal of chrysoberyl $(BeAl_2O_4)$ has been studied in a field of 7800 gauss. The eight Al^{27} sites per unit cell are of two different types. The four sites of the first type have equivalent but differently oriented field gradients; the same is true of the four sites of the second type. However, the field gradients in the two types of sites are not equivalent. That the maximum number of possible lines (40) is not observed can be explained on the basis of crystal symmetry. The symmetry properties, however, give no indication of the orientation of the principal field gradients with respect to the crystal axes. Analysis of variations in the splitting pattern as a function of crystal orientation in an external magnetic field yields the quadrupole coupling constant and the asymmetry parameter for each of the two essentially nonequivalent field gradients as well as the direction cosines defining the orientation of the principal axis system at each of the eight Al^{27} sites.

* Supported by a contract between Air Force Office of Scientific Research and the Ohio State University Research Foundation.

U4. Pure Quadrupole Resonance Spectrum of Al^{27} in $AlBr_3$.* P. A. CASABELLA AND P. J. BRAY, *Brown University.*—The Al^{27} pure quadrupole resonance transitions have been

observed in anhydrous $AlBr_3$. Preliminary measurements give the following values for the transition frequencies:

Transition	Frequency (Mcps)
5/2→3/2	3.73
3/2→1/2	3.01
5/2→1/2	6.74

With the aid of the tables of Livingston and Zeldes[1] the above frequencies yield a coupling constant of 13.5 Mcps and an asymmetry parameter of 74.7%. Because of the high value of the asymmetry parameter the $\frac{5}{2}\rightarrow\frac{1}{2}$ transition acquires an observable intensity.[2] The effective number of unbalanced p electrons for this coupling constant is 0.36, which is in very good agreement with results for Ga and In in GaI_3 and InI_3.[3] The resonances were found with a Pound-Watkins type recording spectrometer.

* This work was supported by a grant from the Research Corporation.
[1] Livingston and Zeldes, "Table of eigenvalues for pure quadrupole spectra, spin 5/2," ONRL Report 1913, Chemistry Division, Oak Ridge National Laboratory.
[2] M. H. Cohen, Phys. Rev. **96**, 1278 (1954).
[3] Barnes, Segel, Bray, and Casabella, J. Chem. Phys. (to be published).

U5. Thermodynamic Functions Associated with a Nuclear Spin System under Steady-State Overhauser Polarization.* E. A. Desloge and W. A. Barker, *St. Louis University*.—Expressions for the steady-state nuclear polarization exhibited by a metal under conditions of electron spin saturation have been derived by numerous authors.[1] We have calculated additional quantities of interest such as the internal energy, entropy, Helmholz free energy, and heat capacity,[2] for the general case in which nuclear relaxations are not restricted to those due to the contact term in the hyperfine interaction alone. These expressions reduce to their well-known thermodynamic equilibrium forms when the electron spin saturation parameter is zero. The nonequilibrium states are interpreted in terms of nonzero chemical affinities rather than spin temperatures.[3]

* This research has been supported in part by a grant from the National Science Foundation.
[1] A. W. Overhauser, Phys. Rev. **92**, 411 (1953); P. Brovetto and G. Cini, Nuovo cimento **11**, 618 (1954); C. Kittel, Phys. Rev. **95**, 589 (1953); W. A. Barker and A. Mencher, Phys. Rev. **102**, 1024 (1956).
[2] W. A. Barker and E. A. Desloge, Bull. Am. Phys. Soc. Ser. II, **2**, 32 (1957).
[3] See E. A. Desloge and W. A. Barker, Phys. Rev. (to be published).

U6. Negative Nuclear Magnetization in Metals.* W. A. Barker and E. A. Desloge, *St. Louis University*.—Under conditions of conduction electron spin saturation nuclei with negative magnetic moment exhibit a negative nuclear magnetization as pointed out by Overhauser.[1] It is interesting to note that the heat capacity[2] associated with this negative magnetization is negative and dominates other contributions to the heat capacity at H/T values of the order of 10^4 oersteds/degree. The negative nuclear magnetization could be detected by nuclear resonance where a stimulated emission would be observed rather than a resonance absorption. It has been pointed out by Mencher[3] that this has some features in common with the solid-state maser proposed by Bloembergen.[4]

* This research has been supported in part by a grant from the National Science Foundation.
[1] A. W. Overhauser, Phys. Rev. **92**, 411 (1953).
[2] W. A. Barker and E. A. Desloge, Bull. Am. Phys. Soc. Ser. II, **2**, 32 (1957).
[3] A. Mencher (private communication).
[4] N. Bloembergen, Phys. Rev. **104**, 324 (1956).

U7. Larmor Frequency Light Modulation by Precessing Sodium Atoms. William E. Bell and Arnold L. Bloom, *Varian Associates*.—We have observed intensity modulation, at the Larmor frequency, of a light beam transmitted through a system of precessing atoms as predicted by Dehmelt.[1] The experiment employs two beams of circularly polarized sodium D light transmitted through a vessel of sodium vapor in argon buffer. The primary light beam, transmitted in the direction of the earth's magnetic field, produces "optical pumping" between the Na ground state Zeeman sublevels, resulting in a net macroscopic moment. The secondary light beam, transmitted perpendicular to the first, pumps at a rate which depends on the instantaneous value of magnetic moment in the secondary beam direction. An applied rf field tips the moment with resulting Larmor precession so that the secondary beam pumping rate, and therefore the intensity of transmitted light, varies at the precession frequency. The transmitted intensity of both beams can be monitored by photocells; that of the primary beam gives M_z and that of the secondary beam gives $M_x \cos\omega t$, where M_x and M_z are defined as usual in magnetic resonance. Resonance is observed at a frequency of 360 kc in a field where the proton Larmor frequency is 2180 cps, agreeing with the spectroscopic g factor of $\frac{1}{2}$ for the Na^{23} atom in a weak magnetic field.

[1] H. G. Dehmelt, Phys. Rev. (to be published).

U8. Effect of Interatomic Interactions on Nuclear Orientation in Paramagnetic Crystals. William R. Wright, *Harvard University*.—The effect of dipolar and exchange interactions on the orientation of a nucleus in a paramagnetic crystal is investigated by considering the statistical average of the moments of the nuclear spin, $\langle I_z^p\rangle_T = [\mathrm{Tr} I_z^p \exp(-\mathcal{H}/kT)/\mathrm{Tr}\exp(-\mathcal{H}/kT)]$. Here p is a positive integer; $\mathcal{H}$ is the spin Hamiltonian of the whole system, nucleus plus crystal. $\mathcal{H}$ is the sum of $\mathcal{H}_0$, which includes the hyperfine interaction and applied magnetic field, and $\mathcal{H}'$, the dipolar and exchange interactions. $\langle I_z^p\rangle_T$ is expanded in powers of $\mathcal{H}'$,[1] and terms beyond the second order are neglected. It is assumed that the effective electronic spin of the paramagnetic ions is one-half. The expressions obtained for $\langle I_z^p\rangle_T$ can be used to calculate the angular distribution of γ radiation from oriented nuclei.[2] The results of applying such a calculation to the experiment of Ambler *et al.*[3] are discussed.

[1] R. Serber, Phys. Rev. **43**, 1011 (1933).
[2] N. R. Steenberg, Proc. Phys. Soc. (London) **A65**, 791 (1952).
[3] Ambler, Hudson, and Temmer, Phys. Rev. **97**, 1212 (1955).

U9. Simple Technique for Studying Spin-Lattice Relaxation Times.* C. F. Davis and M. W. P. Strandberg, *MIT*.—At liquid helium temperatures, spin-lattice relaxation times of paramagnetic salts are frequently as long as milliseconds. Equipment has been built to measure T_1's from recovery times of crystal χ'' after saturation by a magnetron pulse. Experimental technique and observed T_1's will be reported.

* This work was supported in part by the U. S. Army (Signal Corps), the U. S. Air Force (Office of Scientific Research, Air Research and Development Command), and the U. S. Navy (Office of Naval Research).

U10. Proton Resonance in Monolayers of Methane Adsorbed on TiO_2. N. Fuschillo and C. A. Renton, *Pennsylvania State University*.—NMR derivative line shapes have been obtained in methane adsorbed on high surface area TiO_2 at coverages of 0.1, 0.33, 0.50, 0.80, 0.95, and 3.9 monolayer (B.E.T.). The results for bulk methane are in agreement with previous measurements and no change in line width is observed on passing through the λ point at 20.4°K. This result has introduced doubt concerning the hypothesis postulating a rotational transformation at 20.4°K. At a surface coverage of 0.95 monolayer, however, a sharp line width transition is observed ($\Delta H = 4.0$ to 1.0 gauss) at 20.8 ± 0.2°K and ΔH further decreases to 0.3 gauss at 30°K. As the surface coverage is lowered, the ΔH transition becomes progressively more gradual. The line shapes above 20.4°K are complex and are probably best interpreted in terms of a range of reorientation frequencies. The line width ($\Delta H = 5.7$ gauss) and shape for bulk methane are reached at 3.9 monolayer for temperatures below the λ point. At 21.0°K a central discontinuity ($\Delta H = 0.7$ gauss) (i.e., a narrow line component) is present, grows in intensity and narrows as the temperature is raised. The resolved broad line component, however, follows the line

width *versus* temperature data for bulk methane. At coverages of 0.95 monolayer and less the results are consistent with the model of "patchwise" adsorption. The narrow component in the line shapes is associated with diffusional and rotational motions.

U11. Electron Spin Resonance of Radicals Produced by Ultraviolet Irradiation.* HARVEY N. REXROAD† AND WALTER GORDY, *Duke University.*—The radicals produced by ultraviolet irradiation of solutions of various substances in the mixture ether, isopentane, and alcohol (EPA) and frozen at 77°K have been investigated by their microwave electron spin resonance. The EPA mixture, one commonly employed as a solvent by optical spectroscopists, was itself found to give no resonance under uv irradiation at 77°K. A 0.1 M solution of toluene ($C_6H_5CH_3$) in EPA showed a quartet resonance of 80 gauss spread which can be attributed to the CH_2 radical and a single component which might arise from the radical C_6H_5. Thus the results indicate that the uv simply breaks the CC bond which ties the CH_3 to the ring. Interestingly, similar results are obtained for phenol, C_6H_5OH, in EPA. Tentatively, we interpret this to mean that the OH radical is produced by the uv but that it immediately attacks the EPA to form the CH_2 radical and an alcohol. A single moderately sharp resonance is obtained for benzoyl chloride, $C_6H_5(CO)Cl$. This is believed to arise from the C_6H_5CO radical. Probably the Cl produced at the same time would escape through the EPA. Other cases will be discussed. Resonances of radicals produced by uv irradiation have previously been observed by Ingram *et al.*

* Supported by the Office of Scientific Research, U. S. Air Force.
† DuPont Fellow.

U12. Electron Spin Resonance in X-Irradiated Plastics and Synthetic Fibers.* HOWARD SHIELDS, WILLIAM B. ARD, AND WALTER GORDY, *Duke University.*—Microwave paramagnetic resonance has been used to study the effects of ionizing radiation on various plastics and synthetic fibers. The strength of the resonances obtained was found to depend on the degree of crystallinity. A sample of ordinary polyethylene gave no resonance signal after x-irradiation, whereas a similarly irradiated sample of polyethylene (supplied by Phillips Petroleum Company) which has a crystallinity above 90% gave a strong resonance with a seven-component proton hyperfine structure. Strong resonances have been obtained for x-irradiated polystyrene (single sharp line), Teflon (eight-component F^{19} hyperfine structure), Kel-F (unresolved hyperfine structure of several components), polyvinyl fluoride and chlorotrifluoethylene (broad single resonances), polystyrene (single sharp resonance) nylon[1] (asymmetric structure of four components), and Orlon (unresolved hyperfine structure of several components).

* Supported by the Office of Ordnance, U. S. Army, and the Office of Scientific Research, U. S. Air Force.
[1] Resonance in nylon previously detected by E. F. Schneider, Discussions Faraday Soc. **19**, 158 (1955).

Invited Paper

U13. Antiferromagnetic Resonance in Systems with Uniaxial Anisotropy. E. S. DAYHOFF, *U. S. Naval Ordnance Laboratory.* (30 min.)

SATURDAY MORNING AT 9:30

Sheraton-Park, Caribar-Mural Room

(N. AUSTERN presiding)

Theoretical Physics IV: Low-Energy Physics

UA1. Quantitative Evaluation of the Dispersion of Helium. W. F. MILLER* AND ROBERT L. PLATZMAN, *Purdue University.*—A complete and consistent set of oscillator strengths for dipole transitions for the normal helium atom has been derived by analysis of both theoretical and experimental information. The theoretical results of Huang (1948), based upon the momentum matrix element, were adopted as the best obtainable values for the continuum. The oscillator strengths to discrete levels were determined so as to give agreement between the theoretical and experimental value of the static dielectric constant and to be consistent internally, with the sum rule, and with the criterion of continuity at the series limit. The derived oscillator strengths were employed to calculate the following properties of helium gas: various inelastic scattering cross sections for fast electrons, magnetic susceptibility, refractive index, Verdet constant, Van der Waals force, and the mean excitation potential for the stopping power for fast charged particles. The results are in excellent accord with the experimental data available, the comparison being made in part by means of the moments, $F_i = \Sigma f_n (E_n - E_0)^{-i}$, $i = 1,2,\cdots$. The method can also be applied to more complex media.

* Now at Argonne National Laboratory.

UA2. Low-Energy Elastic Scattering of Electrons by Oxygen and Nitrogen.* P. HAMMERLING, B. KIVEL, AND W. W. SHINE, *Avco Research Laboratory.*—The elastic scattering of slow electrons by O and N is calculated by the method of phase shifts. The Hartree potential gives a cross section (2×10^{-16} cm^2) for O on the order of magnitude needed to agree with the experiments of Lamb and Lin[1] in air. This theoretical result should not be taken seriously, since the Hartree potential is known to be too weak as it neglects exchange and polarization. Exchange forces are introduced by a new approximation based on a suggestion of Slater for bound atomic states. The exchange approximation is adjusted to fit the more elaborate calculation of Bates and Massey[2] for zero energy and zero polarization. The addition of a reasonable polarization force results in an acceptable potential and closer agreement with experiment. A similar calculation is made for N. The Hartree potential alone gives a cross section which is too large. The inclusion of exchange and polarization leads to better agreement with the measurements in air.

* Supported by the U. S. Air Force.
[1] L. Lamb and S. C. Lin, "Electrical conductivity of thermally ionized air produced in a shock tube" (to be published).
[2] D. R. Bates and H. S. W. Massey, Trans. Roy. Soc. (London) **A239**, 269 (1943); Proc. Roy. Soc. (London) **A192**, 1 (1947).

UA3. A Variational Wave Function for Heavy Nuclei.* MANUEL ROTENBERG AND LAWRENCE WILETS, *Los Alamos Scientific Laboratory*.—The ground-state energy of an infinite nuclear medium is minimized using a variation wave function consisting of the antisymmetrized product of plane-wave and two-particle cluster functions. The plane-wave states fill the Fermi sea, while in momentum space the two-particle functions are cutoff below the Fermi momentum. This insures the orthogonality between the plane-wave and two-particle states. Furthermore, the centers of mass functions of the two-particle clusters do not overlap, thus insuring complete orthogonality among the particle states. The Hamiltonian consists of two-body interactions plus kinetic terms. The expression for the energy is simple because there are no linked clusters, but the method is limited to potentials with at most soft cores. Numerical examples will be presented and a generalization to include four-particle clusters will be discussed.

* Work supported by the U. S. Atomic Energy Commission.

UA4. Hartree-Fock Solution for the Helium-4 Nucleus.* C. L. SCHWARTZ, *Stanford University*.—In a recent abstract[1] Aviles and Jastrow have reported a Hartree-Fock calculation of the He^4 nucleus using a Yukawa two-body force. They find a binding energy of only 10 Mev, compared with 55 Mev obtained by Irving who used the same force but a more complicated wave function. The purpose of this note is to point out that a large part of this discrepancy lies in the simple kinematical correlation associated with the free motion of the center of mass. If the total translational invariance of the trial function is assured by the unitary transformation previously described,[2] the Hartree-Fock equation is modified only in that the kinetic energy term is multiplied by $\frac{3}{4}$. A variational calculation with a simple one-parameter analytic function then yields a binding energy of 44 Mev; the exact Hartree-Fock solution should give even more binding. Thus, at most, 20% of the binding in Irving's calculation is due to dynamical correlations. The smallness of such correlations is a measure of the validity of the independent particle model.

* This work was supported in part by the Air Force (Office of Scientific Research, Air Research and Development Command).
[1] J. Aviles and R. Jastrow, Bull. Am. Phys. Soc. Ser. II, **2**, 25 (1957).
[2] S. Gartenhaus and C. L. Schwartz, Bull. Am. Phys. Soc. Ser. II, **1**, 383 (1956).

UA5. Refinement of the Brillouin-Wigner Perturbation Method with Tensor Forces.* PAUL GOLDHAMMER, *University of Delaware, Newark*.—The refinement of the Brillouin-Wigner perturbation method[1,2] is applied to the deuteron in third order with both central and tensor forces. The force parameters are chosen arbitrarily to yield an energy eigenvalue near the binding energy of the deuteron. The third-order correction is found to be quite small (approximately 2.9% of the second order). A substantial improvement in the energy eigenvalue is found in third order when one introduces two new variational parameters into the perturbed wave function, one of which multiplies the central and the other the tensor components. The improvement comes primarily from the central components, and is accompanied by a much large admixture of excited S states. The D state admixture is approximately 4.4% in both the second-order and in the third-order calculations when the refinement is applied.

* Assisted in part by the joint program of the U. S. Atomic Energy Commission and the Office of Naval Research.
[1] P. Goldhammer and E. Feenberg, Phys. Rev. **101**, 1233 (1956).
[2] E. Feenberg and P. Goldhammer, Phys. Rev. **105**, 750 (1957).

UA6. Energy Levels in Pb^{208}.† WILLIAM W. TRUE, *Indiana University*.—A detailed shell model analysis of the energy levels of Pb^{208} has yielded excellent agreement with experiment, with a theory in which all parameters are fixed independently of the level scheme being studied. The assumptions underlying the work are: (1) harmonic oscillator wave functions represent the neutron holes; (2) the two-body forces are given by a singlet Gaussian potential whose parameters are determined by the singlet state of the deuteron and the singlet effective range; and (3) the positions of the single-particle levels, including their interaction with the core, are given by the observed levels of Pb^{207}. Configuration interaction has been included and agreement with experiment is improved over that obtained earlier by Alburger and Pryce,[1] who used a delta-function two-body potential and a number of arbitrarily adjusted parameters.

† Supported in part by a grant from the National Science Foundation.
[1] D. E. Alburger and M. H. L. Pryce, Phys. Rev. **95**, 1482 (1954).

UA7. An Effect of Finite Nuclear Size on the Internal Conversion Coefficients.* THOMAS A. GREEN, *Wesleyan University*, AND M. E. ROSE, *Oak Ridge National Laboratory*.—The dependence of the K-shell internal conversion coefficients on the relevant details of nuclear structure has been exhibited. The results for electric and magnetic transitions up to 2^5-pole transitions are expressed approximately in terms of simple nuclear matrix elements which can be evaluated within the framework of any specific nuclear model. The method is similar to that used by Church and Weneser[1] for M–1 transitions. The nature of the approximations made will be discussed and numerical coefficients for the nuclear matrix elements will be given.

* This work was done while one of the authors (T.A.G.) was a research participant at the Oak Ridge National Laboratory.
[1] E. Church and J. Weneser, Phys. Rev. **104**, 1382 (1956).

UA8. Effect of Nuclear Configuration Mixing on Hyperfine Structure Anomalies.* H. H. STROKE, *Princeton University*, AND V. JACCARINO, *Bell Telephone Laboratories*.—The theories of Bohr and Weisskopf[1,2] obtain the hfs anomaly arising from the difference in size and nuclear magnetic dipole moment distribution in two isotopes. The calculation requires the fractional contributions of spin and orbital magnetic moments. These have been obtained in past calculations using a single particle model where large quenching of either orbital or spin magnetism was required to give agreement with experimental magnetic moments. This model did not permit agreement in sign with our measured values of the anomalies $\Delta(Cs^{133-135}) = +0.037 \pm 0.009\%$ and $\Delta(Cs^{135-137}) = -0.020 \pm 0.009\%$.[3] We have calculated these anomalies by considering the effects of nuclear configuration mixing using the theory of magnetic moments of Arima and Horie.[4] By assuming a proton mixture of $(g_{\frac{7}{2}})^3(d_{\frac{5}{2}})^2$ and $g_{\frac{7}{2}}(d_{\frac{5}{2}})^4$ for Cs^{133} and Cs^{135}, and $g_{\frac{7}{2}}(d_{\frac{5}{2}})^4$ for Cs^{137}, and the neutron shells to be filled in the order $s-h-d$, we calculate $\Delta(Cd^{133-135}) = +0.056\%$ and $\Delta(Cs^{135-137}) = -0.019\%$. We find fair agreement with other anomalies when the magnetic moments are also explained.

* This work was partially supported by the U. S. Atomic Energy Commission and the Higgins Scientific Trust Fund.
[1] A. Bohr and V. F. Weisskopf, Phys. Rev. **77**, 94 (1950).
[2] A. Bohr, Phys. Rev. **81**, 331 (1951).
[3] Stroke, Jaccarino, Edmonds, and Weiss, Phys. Rev. (to be published).
[4] A. Arima and H. Horie, Progr. Theoret. Phys. (Japan) **12**, 623 (1954).

UA9. Polarization and Spin-Flip Stripping.* J. C. HENSEL AND W. C. PARKINSON, *University of Michigan*.—Angular distribution of nucleons from the mirror stripping reactions $B^{10}(dp)B^{11}$ and $B^{10}(dn)C^{11}$ have created controversy about the spin assignment of the first excited state of B^{11} and C^{11}. The measurements[1] of Evans and Parkinson, Cerineo, and Maslin *et al.*, indicated that the nucleon was captured with l_n or $l_p = 1$, thereby restricting the spin of the state to $\frac{1}{2} \leq J \leq 9/2$ in disagreement with the theoretical assignment of $J = \frac{1}{2}^-$. A suggestion by French and Evans[2] that the outgoing particle undergoes a "spin-flip" with $\Delta S = 1$ extends the range to $\frac{1}{2} \leq J \leq 11/2$. Polarization measurements of proton groups from the ground and first excited states of B^{11} will be presented to support this hypothesis. Measurements made on the ground states of B^{11} and C^{13} and the first excited state of C^{13} are consistent with a polarization sign $P = (\pm)$ when $j = l \mp \frac{1}{2}$. This

is also in agreement with the results of Juveland.[3] The anomalous first excited state of B^{11} gives opposite polarization indicating the possibility of a spin flip.

* Work supported in part by U. S. Atomic Energy Commission.
[1] Evans and Parkinson, Proc. Phys. Soc. (London) **A67**, 684 (1954); M. Cerineo, Nuclear Phys. **2**, 113 (1956); Maslin, Calvert, and Jaffe, Proc. Phys. Soc. (London) **A69**, 754 (1956).
[2] N. T. S. Evans, Cambridge University thesis (1956).
[3] A. C. Juveland, University of Illinois thesis (1956).

UA10. Evaluation of Slow-Neutron Scattering Parameters for Molecules of Arbitrary Structure. T. J. KRIEGER, *Knolls Atomic Power Laboratory.**—In the Sachs-Teller[1] theory of slow neutron scattering by free molecules, the cross section, σ, for direct scattering by a nucleus may be expressed, in the limit of high neutron energies, as $(\sigma/\sigma_b)=a+b(kT/E)$, where σ_b is the bound cross section of the nucleus, E is the neutron energy, T is the temperature of the scattering system, and the coefficients a and b are constants depending on the associated nuclear "mass-tensor." Analytic expressions for a and b are derived in the general case of arbitrary molecular structure. These are expressed in the form of integrals, which may be evaluated exactly in the case when two principal components of the mass tensor are equal and which then lead to known forms[2] for a and b. In the general case, when all principal components of the mass tensor are unequal, approximate methods can be used for the evaluation of the integrals. The application of such methods to the H_2O molecule is described. For this molecule we find, to 1% accuracy, $a=0.455$ and $b=0.112$.

* Operated for the U. S. Atomic Energy Commission by the General Electric Company.
[1] R. G. Sachs and E. Teller, Phys. Rev. **60**, 18 (1941).
[2] A. M. L. Messiah, Phys. Rev. **84**, 204 (1951).

UA11. Inelastic Scattering Calculations for Nucleons on Nuclei.* C. A. LEVINSON AND M. K. BANERJEE,† *Princeton University.*—A distorted wave calculation for the inelastic scattering of nucleons or nuclei has been carried out on an I.B.M. 704 computer.‡ The distortion efforts are described by a Saxon well with variable parameters. The interaction causing the transition is given by a Yukawa well with variable range and depth. The radial parts of the problem can be cut-off at any radius to simulate surface effects. Typical results will be shown and their dependence on the various parameters will be discussed. A comparison with the $C^{12}(pp')C^{12*}$ $Q=4.4$ Mev experiments of Peele will be given also.

* This work was supported by the U. S. Atomic Energy Commission and the Higgins Scientific Trust Fund.
† On leave of absence from Institute of Nuclear Physics, Calcutta.
‡ The authors are grateful to the Los Alamos Scientific Laboratories for providing the computing facilities.

UA12. Analysis of $(pp'\gamma)$ Angular Correlation on C^{12}.*† M. K. BANERJEE‡ AND C. A. LEVINSON, *Princeton University.*—Neglecting distortions of the plane wave Satchler[1] predicted $(pp'\gamma)$ angular correlation for the excitation of the 4.45-Mev level of C^{12} to be $\sin^2 2\theta$ about the recoil direction. Experiments by Sherr and Hornyak[2] showed the $\sin^2 2\theta$ form but with symmetry axis different from the recoil direction and with appreciable background. It has been shown that the general effect of the distortion is to preserve the $\sin^2 2\theta$ form but it may change the symmetry direction. Calculations of the symmetry direction based on the amplitudes referred to in the previous talk agreed reasonably well with the observed values. It has been shown that the background term depends on the nuclear wave function and the observed values strongly indicates that the C^{12} wave functions are close to the $j-j$ coupling limit.

* This work was supported by the U. S. Atomic Energy Commission and the Higgins Scientific Trust Fund.
† The authors are grateful to the Los Alamos Scientific Laboratories for providing the computing facilities.
‡ On leave of absence from Institute of Nuclear Physics, Calcutta.
[1] G. R. Satchler, Proc. Phys. Soc. (London) **68**, 1047 (1955).
[2] R. Sherr and W. F. Hornyak, Bull. Am. Phys. Soc. Ser. II, 1, 197 (1956).

UA13. Detection of Vacuum Polarization Effects in Scattering of α Particles on Heavy Nuclei. P. SCHWED AND W. RARITA,* *RIAS.*—Previous investigators[1] have shown that by a careful analysis of low energy $p-p$ scattering data it is possible to obtain direct evidence for the modification of the Coulomb field by vacuum polarization effects. In the present work the feasibility of detecting the contribution of this vacuum polarization effect to the scattering of α particles in the 1–10 Mev range of energies on heavy nuclei has been investigated. For the present case, because of the relatively high masses of the particles involved the probability of penetration into the classically forbidden region during a collision is greatly reduced as is consequently the contribution of nuclear interaction when the energy is low enough to provide classically a separation exceeding the range of nuclear forces. The relevant matrix elements for the effect of the vacuum polarization on the scattering have been calculated following the method used by Sommerfeld[2] for bremsstrahlung in order to avoid carrying out numerical integrations directly over the strongly varying Coulomb function.

* Also at Brooklyn College.
[1] L. L. Foldy and E. Eriksen, Phys. Rev. **95**, 1048 (1954); **98**, 775 (1955); Eriksen, Foldy, and Rarita, Phys. Rev. **103**, 781 (1956).
[2] A. Sommerfeld, *Wellenmechanik* (F. Ungar, New York, 1947), Chap. 7.

SATURDAY MORNING AT 9:30

Sheraton-Park, Burgundy Room

(G. S. GOLDHABER presiding)

Unstable Nuclei I

V1. Evidence for Small Deviations from the Allowed Shape in the Comparison of the Beta Spectra of Na^{24} and P^{32}.† F. T. PORTER, F. WAGNER, JR., AND M. S. FREEDMAN, *Argonne National Laboratory.*—Two low Z, similar-in-energy, presumably allowed beta transitions, Na^{24} ($E_0=1394$ kev, $4+\rightarrow 4+$, $\log ft=6.1$) and P^{32} ($E_0=1711$ kev, $1+\rightarrow 0+$, $\log ft=7.9$) have been compared with the Argonne double lens spectrometer at 2% resolution. Vacuum distilled sources on 200 $\mu g/cm^2$ Al had thicknesses of 50 to 75 $\mu g/cm^2$ for Na^{24} and <50 $\mu g/cm^2$ for P^{32}. Considerable attention has been given the question of detector efficiency and instrumental scattering. The results show that Na^{24} has very nearly the allowed shape; its experimental shape factor $[N/f(E_0-E)^2]$ is within 0.5% that given by L_0[1] between 110 and 1300 kev. In contrast the experimental shape factor for P^{32} decreases about 3% from 270 to 1630 kev with a slope $\sim$4 times that of L_0. We conclude that there is definite evidence for small deviations from the allowed shape in one of these transitions, and further, with a

lower confidence level, that the slower P^{32} transition shows the deviation. With Fierz interference ruled out[2] the explanation must be sought elsewhere.

† Based on work performed under the auspices of the U. S. Atomic Energy Commission.

[1] Rose, Perry, and Dismuke, ORNL-1459 Tables.

[2] Schwarzchild, Rustad, and Wu, Bull. Am. Phys. Soc. Ser. II, 1, 336 (1956).

V2. Positron and Gamma-Ray Spectra from the Long-Lived Isomer of Al^{26}. R. G. Johnson and R. D. Moffat, *Lockheed Missile Systems Division.*—The positron spectrum from the long-lived isomer of Al^{26} has been measured with a 4π beta-ray scintillation spectrometer with average source thicknesses of 0.4 mg/cm² and 0.8 mg/cm². The spectrum has been measured previously only by absorption techniques[1] and a 2π scintillation counter with unfavorable source and detector conditions.[2] An allowed Kurie plot of the present data is nonlinear. Analysis using the unique twice forbidden shape factor results in a linear Kurie plot from 0.4 Mev to the end point at 1.13 Mev. Gamma rays with energies of 2.98, 1.84, 1.10, and 0.74 Mev have been observed with a NaI scintillation spectrometer. Handley and Lyon[1] have reported a 0.72-Mev level in Mg^{26} but were unable to obtain coincidences with the other gamma rays associated with the decay. Coincidence studies in the present work show the 0.74-Mev gamma ray to be in coincidence with the positrons; and evidence for a 2.58-Mev level in Mg^{26} will be discussed.

[1] T. H. Handley and W. S. Lyon, Phys. Rev. 99, 755 (1955).
[2] M. J. Laubitz, Proc. Phys. Soc. (London) A68, 1033 (1955).

V3. Gamma-Ray Transitions in Ti^{49}. Ralph E. Segel,* *Aeronautical Research Laboratory, WADC.*—A sample of natural titanium was exposed to a slow neutron beam emerging from the BNL reactor, and the emitted gamma rays observed by two 3-in.×3-in. NaI(Tl) crystals in coincidence in conjunction with a 100-channel pulse-height analyzer and associated electronics. Over 95% of the captures take place in Ti^{48} and therefore the gamma rays observed were due to transitions in Ti^{49}. The following gamma-ray cascades were found, with the number in parentheses indicating the approximate number of cascades per 100 captures: 6.76 − 1.39 (52), 6.55 − 1.59 (8), 6.41 − 0.35 − 1.39 (26), 4.88 − 1.51 − 1.78 (7) (or 4.88 − 1.78 − 1.51), and tentatively, 4.96 − 1.59 − 1.59 (3). The correlation of these data with the high-resolution single spectra of other workers will be discussed.

* Guest scientist at Brookhaven National Laboratory.

V4. Evidence Concerning Excited States in Ga^{70} and Se^{74}. J. W. Butler and C. R. Gosset, *U. S. Naval Research Laboratory.*—A search for low-lying levels in Ga^{70} and Se^{74} has been made by looking for slow neutron thresholds in the $Zn^{70}(p,n)Ga^{70}$ and $As^{74}(p,n)Se^{74}$ reactions, using protons from a 2-Mv Van de Graaff accelerator. The ground-state thresholds were observed to be 1455±5 and 1670±4 kev for Zn^{70} and As^{74}, respectively, in agreement with the measurements of Trail and Johnson.[1] The respective Q values are 1.435 and 1.648 Mev. In the case of As^{74}, an additional threshold was found at a bombarding energy of 1960±5 kev indicating an excited state in Se^{74} at 286±4 kev. No evidence was found for a slow neutron threshold corresponding to an excited state of Ga^{70}, up to the maximum proton energy available, 2 Mev. The region examined in Ga^{70} was from zero to 500 kev of excitation.

[1] C. C. Trail and C. H. Johnson, Phys. Rev. 91, 474(A) (1953).

V5. Decay of Se^{75}.† Noah R. Johnson, *Florida State University and Oak Ridge National Laboratory,* and James B. Cumming and Masami Izawa,* *Brookhaven National Laboratory.*—The decay of the 9.7-day electron-capturing isotope assigned to Se^{75} by Hopkins[1] has been reinvestigated. Sources were prepared by the $(\alpha,2n)$ reaction on isotopically enriched Ge^{70} targets or by the bombardment of As with 380-Mev protons. The Se^{75} and a small amount of Se^{75} were chemically separated from interfering activities. We have confirmed the charge and mass assignment but, in all samples, find the half-life to be 8.40±0.10 days. In addition to x-rays following the electron capture process, we have observed a gamma ray at 45.0±1.0 kev which decays with the Se^{75} half-life. $(x-\gamma)$ and $(x-x)$ coincidence measurements with a resolving time of 0.1 μsec showed that this gamma ray and also the conversion electrons from the transition are in prompt coincidence with x-rays from the electron capture events.

† Research performed under the auspices of the U. S. Atomic Energy Commission.
* Present address: National Institute of Health, Tokyo, Japan.
[1] H. H. Hopkins, Jr., Phys. Rev. 77, 717 (1950).

V6. Decay of Y^{93} (11 Hour).* R. L. Heath, *Phillips Petroleum Company.*—The beta and gamma rays emitted in the decay of Y^{93} have been studied with single crystal and coincidence scintillation spectrometers. This activity was isolated as a fission product from U^{235} irradiated in the MTR. Using a 3 in.×3 in. NaI detector the following gamma rays were observed to follow a half-life of 11.0±0.4 hr: 0.265±0.005, 0.455±0.008, 0.675±0.01, 0.940±0.01, 1.15±0.02, 1.40±0.02, 1.88±0.02, and 2.14±0.02 Mev. The relative intensities of these gamma rays were found to be 1.00, 0.034±0.006, 0.151±0.015, 0.366±0.04, 0.053±0.01, 0.097±0.015, 0.23±0.023, and 0.085±0.01, respectively. Beta-ray branching ratios, determined by comparison of 4-pi beta determinations with gamma-emission rates, indicated that the 3.1-Mev beta transition to the ground state accounts for 85% of the transitions. Gamma-gamma coincidence measurements were made and yielded results consistent with a decay scheme with levels in Zr^{93} at 0.265, 0.940, 1.40, and 2.14 Mev. This level scheme will be discussed.

* This work was performed under the auspices of the U. S. Atomic Energy Commission.

V7. Gyromagnetic Ratio of the 3.5×10^{-9} sec State of Tc^{99} by Angular Correlation Techniques.* S. Raboy and V. E. Krohn, *Argonne National Laboratory.*—A preliminary result of +1.9±0.5 nuclear units has been obtained for the gyromagnetic ratio of the 181-kev state of Tc^{99}. The sources were prepared by neutron irradiation of natural molybdenum which was subsequently dissolved in nitric acid. Coincidences were observed between the 780- and 181-kev gamma rays following the beta decay of 67-hr Mo^{99} and their anisotropy was measured as a function of the magnetic field applied perpendicularly to the plane of the gamma rays. Information about the attenuation of the nuclear correlation by random fields in the liquid sources has not yet been obtained, but the short lifetime of the intermediate nuclear state suggests that the attenuation is probably negligible for the purposes of the present measurement.

* Work performed under the auspices of the U. S. Atomic Energy Commission.

V8. Gyromagnetic Ratio of the 10^{-8} sec State of Ta^{181}.† V. E. Krohn and S. Raboy, *Argonne National Laboratory.*—The gyromagnetic ratio of the 10^{-8} sec state of Ta^{181} was measured by observation of the perturbation of the angular correlation pattern by a magnetic field. The study was performed on neutron-irradiated hafnium metal dissolved in hydrofluoric acid. Independent measurements were performed to study the attenuation of the pattern by the liquid field. The gyromagnetic ratio was found to be +1.23±0.05 nuclear units.

† Work performed under the auspices of the U. S. Atomic Energy Commission.

V9. Gamma Radiation from Long-Lived Rhodium Isotopes.* N. Goldberg, *Washington University and University of*

Pennsylvania.—The gamma radiation from long-lived rhodium isotopes made by deuteron bombardment of ruthenium were studied with a coincidence scintillation spectrometer. Farmer has reported that the activity is a mixture of 210 day Rh^{102} and a longer lived isotope with $A<102$. We have made angular correlation measurements for the 125- and 198-kev transitions which are from the latter activity and found the correlation corrected for solid angle to be $W(\theta)=1+(0.184\pm0.018)\times P_2(\cos\theta)+(0.016\pm0.023)P_4(\cos\theta)$. Measurements of the internal conversion coefficient by Stirling[1] indicate that they are either dipole or quadrupole. An unsuccessful search for a crossover transition suggests that the spins of the three state are a monotonic series. The correlation measurement rules out $J\pm4\rightarrow J\pm2\rightarrow J$. Measurements of the gamma rays from Rh^{102} determined the following coincident pairs: (475, 1040), (475, 630), (475, 766), (630, 766), and (695, 1105). A decay scheme for Rh^{102} is proposed.

* Supported in part by the Office of Naval Research and Office of Ordnance Research, U. S. Army.
[1] W. L. Stirling, Ph.D. thesis, Washington University 1956 (unpublished).

SATURDAY AFTERNOON AT 1:30

Sheraton-Park, Burgandy Room

(R. W. HAYWARD presiding)

Unstable Nuclei II

W1. Effect of the Static Nuclear Quadrupole Interaction in Indium. R. M. STEFFEN, *Purdue University.*—The interaction between the nuclear quadrupole moment and the electrostatic gradient of the tetragonal indium lattice is responsible for a strong attenuation of the $In^{111}-Cd^{111}$ gamma-gamma correlation displayed by sources of metallic indium.[1] Precise measurements of this attenuation in the temperature range from 83°K to 418°K allowed the computation of the quadrupole "precession" frequency ω which is proportional to the electric gradient in the crystal. Some representative values obtained for ω are: $T=83$°K, $\omega=(23\pm3)$ Mc/sec; $T=300$°K, $\omega=(13.6\pm0.4)$ Mc/sec; $T=418$°K, $\omega=(11.4\pm0.7)$ Mc/sec. The temperature effect of ω can be related to the decrease in the axial ratio c/a of the tetragonal indium cell with increasing temperature[2]: 83°K, $c/a=1.082$; 300°K, $c/a=1.075$; 418°K, $c/a=1.064$. However, calculations of the crystalline gradient based on a simple model show that, whereas the variation of ω between 230°K and 418°K can be accounted for by the change of c/a, the variation of ω at lower temperatures is too large to be explained by the change of the lattice spacing. Possible interaction mechanisms which may become important at lower temperatures will be discussed.

[1] R. M. Steffen, Advances in Phys.; Phil. Mag. Suppl. **4**, 293 (1955).
[2] Graham, Moore, and Raynor, J. Inst. Metals **84**, 86 (1955–1956).

W2. Decay of Ba^{131}. L. S. AUGUST, R. W. CAMPBELL, AND MAX GOODRICH,* *Louisiana State University.*—The decay of the electron-capture isotope Ba^{131} has been studied by measurement of its electron spectrum with a double-focusing magnetic spectrometer using high specific activity sources made by (n,γ) on enriched Ba^{130}. In addition, a reinvestigation of the $\gamma-\gamma$ coincidence spectra has been made with 3-in.×3-in. NaI scintillation spectrometers. In both experiments the energies determined by Cork *et al.*[1] for the four prominent gamma rays (123.8, 215.8, 373, 497 kev) were used for calibration. Eleven other gamma rays belonging to the Ba^{131} decay were observed in one or both spectrometers (90, 133, 158, 239, 249, 405, 585, 620, 830, 915, 1040 kev). Of these, the 158-kev and 405-kev have not previously been reported. Several other very weak lines were indicated but have not been certainly identified as gamma rays in the Ba^{131} decay. Internal conversion coefficients and relative intensities of the gamma rays were determined and an improved decay scheme proposed.

* Supported by the Research Corporation.
[1] Cork, LeBlanc, Nester, and Brice, Phys. Rev. **91**, 76 (1953).

W3. Levels in Gd^{155}.* F. BOEHM AND E. N. HATCH,† *California Institute of Technology.*—The gamma-ray spectrum of Gd^{155} following the 1.7-yr beta decay from Eu^{155} has been investigated with the two-meter curved-crystal gamma-ray spectrometer and the semicircular beta-ray spectrometer. The Eu^{155} was produced by double neutron capture in an Eu_2O_3 sample enriched in Eu^{153}. Following are the energies in kev and the multipolarities of the measured gamma-rays from Gd^{155}: $18.9\pm0.1\,M1+E2$; $26.5\pm0.3(E1)$; $45.29\pm0.01(E1)$; $60.00\pm0.02\,M1+E2$; $86.54\pm0.01E1$; $105.32\pm0.03E1$. The following conclusions can be drawn with respect to the level assignment in Gd^{155}. The first rotational state[1] ($\frac{3}{2}$-, $K=\frac{3}{2}$) has an energy of 60.00 kev above ground state. Two intrinsic levels with positive parity and probable spins $\frac{1}{2}$ and $\frac{5}{2}$ have energies of 86.54 kev and 105.32 kev, respectively. The proposed spin assignments are in agreement with the observed branching ratios.

* Work supported by the U. S. Atomic Energy Commission.
† Present address: Brookhaven National Laboratory.
[1] E. L. Church, Bull. Am. Phys. Soc. Ser. II, **1**, 180 (1956).

W4. Decay of Tb^{160}. M. A. CLARK AND J. W. KNOWLES, *Chalk River Laboratories.*—Gamma rays, conversion electrons, and beta rays from the decay of Tb^{160} (73*d*) have been examined in beta spectrometers of 2% and 0.6% resolution in a NaI scintillation spectrometer and a curved-crystal gamma spectrometer. Beta transitions have been observed with maximum energies of 56 ± 15, 860 ± 15, and about 1700 kev, and intensities of $58\pm7\%$, $38\pm7\%$, and $<2\%$ per disintegration, respectively. The absence of gadolinium K x-rays sets an upper limit of $\frac{1}{4}\%$ of the disintegrations for the K-capture process in Tb^{160}. Table I gives K/L ratios and K-conversion coefficients for a number of the gamma-ray transitions. The interpretation of levels in Dy^{160} will be discussed.

TABLE I.

E_γ (kev)	Relative I_K	Relative I_γ	K/L	α_K
K x-rays	...	147	...	...
86.7	67.6	100	0.68 ± 0.07	1.50 ± 1
197	2.44	31	2.3 ± 0.08	0.18 ± 0.04
216	0.46	25	7.2 ± 1.8	0.041 ± 0.01
299	1.15	197	>4	0.013 ± 0.003
880	0.31	225	>4	$(3.0\pm0.6)\times10^{-3}$
966	0.30	262	>5	$(2.5\pm0.5)\times10^{-3}$
1179	4.4×10^{-3}	114	>4.5	$(6.6\pm1.3)\times10^{-4}$
1274	1.7×10^{-3}	62	...	$(6.1\pm1.2)\times10^{-4}$

W5. Decay of Ta^{177}.* L. G. MANN, R. J. NAGLE, AND H. I. WEST, *University of California, Livermore.*—Ta^{177} (56-hr half-life) was produced by the $Lu^{176}(\alpha,2n)Ta^{177}$ reaction using

34-Mev alphas and the Hf(p,n)Ta reaction using 12-Mev protons. The former method was preferred because of greatly reduced Ta^{179} yield. The decay is by orbital electron capture and $\sim 2\times 10^{-3}$% positron emission. Coincidence experiments and gamma- and beta-ray spectroscopy measurements were carried out using scintillation detectors, a thin-lens beta-ray spectrometer, and a 256-channel pulse-height analyzer. Levels in Hf^{177} were found at 1070 and 745 Mev in addition to those previously observed at 321 and 113 kev in the Lu^{177} decay.[1,2] Gamma rays of 113, 208, 321, 425, 510, 630, 745, 955, and 1070 kev were observed. The ratio of $K/K+L$ electron capture to the 1070-kev level was 32%, giving a decay energy of 85 kev to that level and 1155 kev to the ground state. The level scheme in Hf^{177} will be discussed.

* This work was performed under the auspices of the U. S. Atomic Energy Commission.
[1] Tor Wiedling, "Directional correlation measurements and some other related investigations of excited nuclei," Ph.D. thesis, University of Stockholm (1956).
[2] P. Marmier and F. Boehm, Phys. Rev. **97**, 103 (1955).

W6. Fine Structure in the Decay of Hg^{198}.* BERNARD HAMMERMESH AND ROBERT K. SMITHER, *Argonne National Laboratory.*—In the course of our investigation of the capture gamma-ray spectrum from gold with the Argonne 7.7-meter bent-crystal spectrometer,[1,2] we have studied the gamma rays which follow the beta decay of Au^{198} to Hg^{198}. It appears that the second excited state of Hg^{198} is really a very close doublet. This state is about 1.09 Mev above the ground state.[3] It decays to the ground state either directly or through the first excited state at 412 kev.[3] In the latter case a gamma ray of about 675 kev is emitted.[3] This line has been found to be a doublet. It consists of one line at 671.1 kev and one line at 678.9 kev. The first line is about three times as intense as the second line. In addition, the line at 1.09 Mev has been studied and has been found to be too wide to be a single line.

* Work performed under the auspices of the U. S. Atomic Energy Commission.
[1] B. Hamermesh, Bull. Am. Phys. Soc. Ser. II, 1, 220 (1956).
[2] Hamermesh, Rose, and Smither, Bull. Am. Phys. Soc. Ser. II, 1, 346 (1956).
[3] L. G. Elliott and J. L. Wolfson, Phys. Rev. **82**, 333(A) (1951).

W7. Decay of Bi^{205}.* STANLEY H. VEGORS, JR., AND R. L. HEATH, *Phillips Petroleum Company.*—The gamma rays emitted by 15-day Bi^{205} have been studied with single-crystal and coincidence scintillation spectrometers. Using the 569.7-kev gamma ray in Bi^{207} and the 703.3-kev gamma ray in Bi^{203} as energy standards, the following gamma rays have been observed (intensities per 100 Pb K x-rays are given in parentheses): 280±10 (2.8); 330±15 (0.86); 383±15 (0.4); 470±30 (1.5); 511, positrons (~0.4); 518±15 (~5); 570±15 (~10); 621±15 (2.2); 703.3 (34.5); 755±15 (~7); 910±10 (7.7); 990±10 (20.2); 1040±15 (17.9); 1182±15 (3.5); 1350±30 (~2); 1515±20 (3); 1620±20 (6.4); 1757±15 (41.3); and 1870±20 (10.1). Of the major transitions, the 1870-, 910-, and 280-kev gamma rays are in coincidence with the 703.3-kev gamma ray, the 703.3 is in coincidence with the 1870, and the 703.3 is in coincidence with the 910-kev gamma ray. No major gamma rays are in coincidence with the 1757-kev transition. These data imply the following levels in Pb^{205}: 703.3, 990, 1620, 1757, and 2573 kev. Implications of these measurements will be discussed.

* This work performed under the auspices of the U. S. Atomic Energy Commission.

W8. Comparison of Various Gamma-Ray Conversion Processes Useful in High-Resolution, Low-Energy Beta-Ray Spectrometers. DAVID B. BEARD, *Lockheed Aircraft Corporation.*—The measure of the efficiency of any process by which gamma rays are converted to counted electrons is taken to be the cross section for production by the initial gamma ray of an electron or electrons of unique energy within the acceptance angle of the beta-ray spectrometer. For contiguous source and converter, the photoelectric effect yields an efficiency number approximately $0.2P^{-1}\sigma_{PA}$, where P is the resolving power and σ_{PA} is the total photoelectric cross section. The Compton effect is shown to be negligibly efficient. Pair production requires limiting two solid angles, but, since the angular correlation of the two electrons and the cross section increase with gamma-ray energy, pair production becomes more efficient than the photoelectric effect at gamma-ray energies well in excess of 10 Mev. The energy at which this occurs depends upon the resolution sought. The efficiency number for pair production is $0.1P^{-1}\sigma_{PA}f$, where σ_{PA} is the total pair production cross section and f is the fraction of pairs to the total number of single pair-produced electrons within the energy interval which reach the detector. Depending on both energy and resolution f may vary from $0.2P^{-1}$ to one.

SATURDAY AFTERNOON AT 1:30

Sheraton-Park, Continental Room

(K. L. DUNNING presiding)

Fast Neutron Reactions

X1. Measurement of Total and Differential Cross Sections by Fast Coincidence Detection of D-D Neutrons and Their Helium-3 Recoils.* ELBERT W. BENNETT, PABLO L. OKHUYSEN, JOHN B. ASHE, AND WALTER E. MILLETT, *The University of Texas.*—One-hundred kev deuterons strike an occluded deuteron target. The neutrons and a collimated beam of helium-3 recoils are detected in coincidence. The helium-3 recoils are detected with anthracene and the neutrons with terphenyl-toluene scintillators. The ratio of coincidences in the defined beam to that out of the beam is about one thousand. The total cross sections of several elements and the differential cross section of lead for 2.7-Mev neutrons have been measured.

* This research was supported by the U. S. Air Force through the Air Force Office of Scientific Research of the Air Research and Development Command under contract.

X2. Total Neutron Cross Section of Al in the kev Region.* CARL T. HIBDON, *Argonne National Laboratory.*—The neutron cross section of Al up to 415 kev shows resonances at the following energies in kev (starred ones have not been previously reported—the numbers in parentheses following each energy value give probable values of J and the lowest possible values of l):—36 (3,0), 89 (3,0), 120 (3,1)*, 145 (3,0), 149 (1,1)*, 152 (0,2)*, 158 (4,1), 205 (2,1), 212 (1,1)*, 223 (1,1)*, 229 (0,2)*, 256 (0,2)*, 280 (3,0), 288 (1,1)*, 300 (1,1)*, 313 (2,1), 317 (0,2)*, 366 (3,1), 373 (1,1)*, 386 (2,0)*, and 410 (2,1). The resonance near 36 kev has a measured peak height above 28 barns and by self-detection a peak height near 40 barns. The width is about 1.5 kev. The peak near 89 kev has a height above 18 barns and appears to consist of at least two

resonances:—one is attributable to s-wave neutron interaction. At 120 kev a symmetrical peak having a width near 2.5 kev was resolved to a height above 11 barns. The group of four peaks in the region from 140 to 165 kev do not show any interference.

* Work performed under the auspices of the U. S. Atomic Energy Commission.

X3. Measurements of Neutron Groups from $Cu^{65}(p,n)Zn^{65}$ by Time of Flight.* H. H. Landon, A. J. Elwyn, and G. N. Glasoe, *Brookhaven National Laboratory.*—The $Cu^{65}(p,n)Zn^{65}$ reaction has been studied using 2.9-Mev protons from the BNL 18-inch cyclotron. Neutron groups are detected, and their energies measured by time-of-flight techniques, utilizing the natural phase bunching of the protons in the cyclotron.[1] A new time-to-pulse height converter[2] is used in conjunction with a 100-channel quartz line pulse-height analyzer. The operation of the time converter is based on an rf vernier technique which permits the timing of an event in a fast plastic phosphor with respect to the phase of the 20-Mcps cyclotron rf. Neutron groups from proton bombardment on thin evaporated copper targets have been observed giving energy levels in Zn^{65} in approximate agreement with results[3] recently reported for this reaction by a different technique.

* Work performed under the auspices of the U. S. Atomic Energy Commission.
[1] Muehlhause, Bloom, Wegner, and Glasoe, Phys. Rev. **103**, 720 (1956).
[2] The design of the time converter is due to R. L. Chase and W. A. Higinbotham (to be published).
[3] E. M. Bernstein and H. W. Lewis, Bull. Am. Phys. Soc. Ser. II, **2**, 61 (1957).

X4. Elastic Scattering of 14-Mev Neutrons.* J. H. Coon, R. W. Davis, H. E. Felthauser, and D. B. Nicodemus,† *Los Alamos Scientific Laboratory.*—Previous experiments[1] on the elastic scattering of 14-Mev neutrons have been continued, and differential cross sections have now been measured in the angle range from 6° to 140° for Pb, Sn, Cu, and Fe. A ring scattering geometry was employed with a D–T neutron source and a small recoil-proton scintillation detector whose pulse height spectrum was recorded in an 18-channel analyzer. Inelastic events in which the neutron loses an energy of more than a few hundred kev were discriminated against by detailed comparison of the pulse-height spectrum due to scattered neutrons with the pulse-height spectrum due to primary source neutrons. For angles less than 90° the present measurements are in fairly good agreement with optical model calculations reported by Beyster.[2] However, for angles greater than 90° the calculated curves have higher maxima and lower minima than do the experimental curves, the difference being typically about a factor of two.

* Work performed under the auspices of the U. S. Atomic Energy Commission.
† On leave from Oregon State College.
[1] J. H. Coon and R. W. Davis, Phys. Rev. **94**, 785(A) (1953).
[2] J. R. Beyster (private communication).

X5. Differential Elastic Scattering of 14-Mev Neutrons by Pb and Bi.* L. A. Rayburn, *Argonne National Laboratory.*—Absolute differential cross-section measurements have been made in the angular interval from 10° to 75° in the laboratory coordinate system with an angular resolution of about ±3.5°. A collimated beam of 14-Mev neutrons is obtained from the $H^3(d,n)He^4$ reaction by collimating the alpha particles from the reaction and then counting neutron, alpha coincidences. A time-of-flight circuit is used in conjunction with a triple fast-slow coincidence circuit in order to obtain an over-all resolving time of about 3 millimicroseconds. The experimental arrangement will be described and the aforementioned cross-section measurements will be presented.

* Work performed under the auspices of the U. S. Atomic Energy Commission.

X6. Elastic Scattering of 14-Mev Neutrons on Be and N.* J. D. Anderson, C. C. Gardner, M. P. Nakada, and C. Wong, *University of California, Livermore.*—A time-of-flight method has been used to measure the elastic scattering of 14.2±0.5-Mev neutrons on Be and N in the angular range 30° to 140°. A 14-cm-radius scattering ring having 5 cm×5 cm rectangular cross section was utilized. The neutron detector was a stilbene scintillator biased at 1 to 2 Mev. The primary uncertainty in the cross section is the ability to separate the elastic neutrons from those scattered from the first excited state. The N cross section was obtained by a Melamine, CH_3 subtraction. The errors are about 20% including line shape, but does not include multiple scattering corrections. The Be cross sections from 30° to 140° in 10° steps are 202, 130, 69, 31.2, 21.7, 16.1, 17.0, 15.9, 17.0, 15.3, 12.9, and 9.8 millibarns per steradian. The N data are in reasonable agreement with a previous cloud-chamber experiment.[1]

* Work performed under auspices of the U. S. Atomic Energy Commission.
[1] J. R. Smith, Phys. Rev. **95**, 730 (1954).

X7. Large-Angle Elastic Scattering of 14.6-Mev Neutrons on Medium A Nuclei.* C. C. Gardner, J. D. Anderson, M. P. Nakada, and C. Wong, *University of California, Livermore.*—A time-of-flight method has been used to measure the elastic scattering of 14.6-Mev neutrons on Ag, Cd, and Sn in the angular range 90° to 165° in 5-degree steps. A 1-meter-radius scattering ring having 10×2 cm rectangular cross section was fixed in position at 47° to the tritium target. The neutron detector was a plastic scintillator biased at 11 Mev, and movable along the axis of the ring to vary the scattering angle. A 10-in. Hevimet (W) rod placed between target and detector attenuated the direct neutrons. The method depends on the fact that neutrons transmitted through the W and small-angle air-elastic neutrons are time-separated from the elastic neutrons. For example, at 145° this time amounts to about 45 mμ sec, while the resolution of our time-of-flight equipment, as measured by the full width at half-maximum of the elastic neutron peak, amounts to about 4 mμ sec. The relative cross sections for Sn from 90° to 165° in 5-degree steps are as follows: 25.8, 28.3, 20.2, 23.6, 20.5, 17.5, 13.6, 9.4, 11.5, 19.7, 20.8, 18.4, 14.7, 13.2, 16.7, 24.3, and 21.4. The relative counting errors were about 10% and the angular resolution was about ±2°.

* This work was done under the auspices of the U. S. Atomic Energy Commission.

X8. Differential Cross Section for 3.7-Mev Neutrons Elastically Scattered from Copper, Nickel, and Zinc.* M. K. Machwe,† H. S. Hans,‡ D. W. Kent, Jr., and S. C. Snowdon, *Bartol Research Foundation.*—The differential cross sections for the elastic scattering of 3.7-Mev neutrons from copper, nickel, and zinc have been measured in a ring geometry using a plastic scintillation detector. The measurements were taken over an angular range of 126 degrees between 18° and 144°. Corrections have been applied for the energy sensitivity and angular sensitivity of the detector. Angular resolution effects have been removed by iteration. As yet multiple scattering effects have not been removed but will be corrected for by a Monte Carlo type calculation.

* Assisted by the U. S. Atomic Energy Commission.
† On leave from the University of Delhi.
‡ Now at Muslim University, Aligarh.

X9. Angular Distributions of Neutrons from $Al^{27}(d,n)Si^{28}$.* A. G. Rubis,† *Boston University.*—A thin aluminum target was bombarded with 2.16-Mev deuterons from the MIT-Rockefeller Van de Graaff generator. The neutron spectrum has been measured at eight angles to the incident deuteron beam by means of nuclear emulsions. Eleven states of Si^{28} have been observed,[1] and angular distributions have now been

obtained for eight of these states. Most of these angular distributions are fairly isotopic, except for neutrons emitted to the 8.57- and 9.36-Mev excited states. The relation of these distributions to the stripping mechanism will be discussed. The reaction has also been studied at 6.00-Mev bombarding energy, with deuterons from the MIT–ONR Van de Graaff generator. Preliminary results of a Butler theory analysis of the angular distributions obtained at this energy will be presented.

* Supported in part by the U. S. Air Force through the Air Force Office of Scientific Research of the Air Research and Development Command.
† Part of this work was done at Brookhaven National Laboratory while the author was a summer guest.
[1] Rubin, Ajzenberg-Selove, and Mark, Phys. Rev. **104**, 727 (1956).

X10. Polarization of Neutrons from the $C^{12}(d,n)N^{13}$ Reaction.* W. Haeberli† and W. W. Rolland, *Duke University*.—Targets of natural carbon, about 200 kev thick, were bombarded with deuterons of energy 2.5 to 3.6 Mev. Neutrons emerging at an angle θ_1 with respect to the deuteron beam are scattered by a carbon cylinder 2.8 cm in diameter. Neutrons scattered in the reaction plane by an angle θ_2 are detected by a Lucite-ZnS scintillator. From the number of neutrons scattered to the left and right, and the $C^{12}(n,n)C^{12}$ phase shifts,[1] the neutron polarization may be deduced. For $E_d=2.95$ Mev, $\theta_1=20°$, the left-right asymmetry was measured as a function of θ_2. The observed angular dependence agrees well with calculated values if it is assumed that the neutrons emerging from the reaction have a polarization $P=-(32\pm5)\%$. For $E_d=2.95$ and 3.15 Mev the polarization was determined for different values of θ_1 between 0° and 60°. At both energies the polarization rises rapidly from 0° to 10°, reaches a flat maximum of $P\sim-30\%$ at $\theta_1\sim20°$ and drops to $P\sim-10\%$ at 60°. Measurements for $\theta_1=20°$, $E_d=2.5$ to 3.6 Mev, indicate that the polarization remains between -15% and -30% in this energy interval. A more accurate statement is not possible, since the $C^{12}(n,n)C^{12}$ phase shifts appear rather uncertain at the lower energies.

* Work supported by the U. S. Atomic Energy Commission.
† Now at the University of Wisconsin.
[1] Meier, Scherrer, and Trumpy, Helv. Phys. Acta **27**, 577 (1954).

X11. Scattering of Polarized Neutrons from Intermediate and Heavy Nuclei.* S. E. Darden, J. D. Clement, and F. Borelli, *University of Wisconsin*.—Measurements of the polarization produced in the scattering of 380-kev neutrons from heavy nuclei have been continued. In addition measurements have been carried out at a neutron energy of 1 Mev. The $Li^7(p,n)Be^7$ reaction was used as a source of polarized neutrons.[1,2] Left-right asymmetries in scattering of these neutrons from several elements ranging in atomic weight from 55 to 238 were measured at scattering angles of 55°, 90°, and 130°. With few exceptions the observed polarizations vary smoothly with atomic weight. Measured values of the polarization range from -0.07 to $+0.15$ at 380 kev, and from -0.20 to $+0.15$ at 1 Mev. The results at 380-kev neutron energy were compared with values predicted by the complex square well potential modified by a surface spin-orbit interaction. Using several sets of well parameters it has not been possible to reproduce the experimental results.

* Work supported by the U. S. Atomic Energy Commission and by the Graduate School from funds supplied by the Wisconsin Alumni Research Foundation.
[1] A. Okazaki, Phys. Rev. **99**, 55 (1955).
[2] See preceding abstract.

X12. Polarization of 1-Mev Neutrons from the $Li^7(p,n)Be^7$ Reaction.* H. R. Striebel and W. Haeberli, *University of Wisconsin*.—The polarization P_1 of 0.8- to 1.4-Mev neutrons emitted from the $Li^7(p,n)Be^7$ reaction at a laboratory angle of 50° has been investigated. The left-right asymmetry $1-P_1P_2/1+P_1P_2$ in the scattering of neutrons from a liquid oxygen sample was measured at a scattering angle of 55° for seven neutron energies and at 90° for two neutron energies. P_2 was calculated using phase shifts extracted from the oxygen total cross section[1] and the level parameters[2] for the 1-Mev and 1.30-Mev resonances. Using a 60-kev Li target, values of P_1 between -0.20 and -0.40 were obtained in the energy region investigated. In addition, measurement of left-right asymmetries with carbon as a scatterer provided information on the carbon scattering phase shifts at 1.0 and 1.4 Mev. The observed D-wave splitting of about 1° at 1 Mev may be interpreted as the effect of the wide $\frac{3}{2}^+$ resonance[2] at 3.65 Mev. The sign of the P-wave splitting is the same as has been found at higher neutron energies.[3]

* Work supported by the U. S. Atomic Energy Commission and by the Graduate School from funds supplied by the Wisconin Alumni Research Foundation.
[1] Bockelman, Miller, Adair, and Barschall, Phys. Rev. **84**, 69 (1951).
[2] R. K. Adair, Phys. Rev. **92**, 1491 (1953).
[3] Meier, Scherrer, and Trumpy, Helv. Phys. Acta **27**, 577 (1954).

X13. Measurement of Anisotropic Neutron Flux with Proton Recoils in Nuclear Emulsions.* J. H. Roberts, *Northwestern University*.—The absolute neutron flux $F(E_n)$ can be determined by measuring the proton recoil spectrum for protons emitted in all directions from the equation

$$F(E_n)=\frac{E_n}{n\sigma(E_n)}\frac{dM(E_p)}{dE_p},$$

where E_n is the neutron energy, n the atomic hydrogen density in the volume detector, $\sigma(E_n)$ the n-p scattering cross section, and $M(E_p)$ the number of proton recoils per energy interval per unit volume of detector. The expression is independent of neutron direction. Rotated 200 micron C2 plates were exposed to 0.8- and 1.3-Mev neutrons from $Li^7(p,n)$. Plate shrinkage was minimized by treating the plates with rosin. About 4000 tracks were measured. Two well-resolved peaks with a width of ~150 kev at half-maximum were obtained. The statistical accuracy of the neutron flux in the two peaks is about ten percent.

* Work supported by Argonne National Laboratory.

Saturday Afternoon at 1:30

Shoreham, Main Ballroom

(V. L. Fitch presiding)

Heavy Mesons and Hyperons II

Y1. Hyperfragments from K^--Meson Stars in Emulsion.* Fred W. Inman, *University of California, Berkeley*.—Analysis of 1900 K-meson stars in emulsion stacks exposed to the enriched negative K^- meson beam[1] of the Bevatron has yielded 12 mesonic and 45 nonmesonic hyperfragment decays. A program for the IBM 650 data-processing machine has been written and used to calculate all possible decay schemes of some of these hyperfragments. In some cases the K^--meson

capture process is also analyzed to aid in the identification of the hyperfragment. Photometric measurements are also used in track identification. The prong distribution of the hyperfragment decays is 1:2:3:4:5:6—6:20:17½:8:3½:2. Of these, twelve are mesonic with prong distribution 2:3:4—6:5:1. Detailed analysis of the events has yielded the following decay schemes and binding energies for the Λ^0 hyperon: $_\Lambda H^4 \rightarrow {}_2He^4 + \pi^- + Q$ (2 events), B.E. $= 1.1 \pm 0.7$ Mev; $_\Lambda He^4 \rightarrow He^3 + H^1 + \pi^- + Q$, B.E. $= 1.2 \pm 1.0$ Mev; $_\Lambda He^5 \rightarrow H^1 + \pi^- + He^4 + Q$, B.E. $= 3.0 \pm 0.6$ Mev; $_\Lambda Li^8 \rightarrow \pi^- + 2He^4 + n + Q$, B.E. $= 3.8 \pm 3.0$ Mev.

* This work was done under the auspices of the U. S. Atomic Energy Commission.
† Barkas, Dudziak, Giles, Heckman, Inman, Mason, Nickols, and Smith, UCRL-3627 (December, 1956), and Phys. Rev. (to be published).

Y2. Negative K Capture by Nuclei.* R. H. Capps, *University of California, Berkeley.*—The experimental data of White, Gilberg, and Violet,[1] concerning the charged sigma particles emitted when negative kayons are stopped in photographic emulsions, are interpreted by means of an optical model. It is assumed that the primary absorption interaction involves directly only a single nucleon, and that the impulse approximation is valid in this interaction. In this model the observed spectra of Σ^+ and Σ^- particles emitted in two-prong stars are best explained if one assumes an attractive scattering interaction between sigma particles and nucleons. From a comparison of the emulsion data with the results of stopping negative kayons in a hydrogen bubble chamber,[2] limits are placed on the possible magnitude of the cross section in nuclei for the absorption of charged sigma particles by means of conversion to neutral sigma or lambda particles.

* This work was done under the auspices of the U. S. Atomic Energy Commission.
[1] White, Gilbert, and Violet, (to be published).
[2] Alvarez, Bradner, Falk-Vairant, Gow, Rosenfeld, Solmitz, and Tripp, "K^- interactions in hydrogen," UCRL-3583 (November, 1956) (to be published).

Y3. Probable Nuclear Interaction of a Hydrogen Hypernucleus.* R. Levi-Setti† and W. Slater, *The University of Chicago.*—In the interaction of a 4.5-Bev π^- in nuclear emulsion, a gray track (A) is emitted, which at a point 2.4 mm from its origin yields a helium hypernucleus (B) and no other visible track. B, whose range is 4 mm, is identified by estimates of its charge (from δ rays, $Z=2$), and mass (from constant sagitta scattering, $M_B = 4.5 \pm 1.5 M_P$), and by its decay at rest into $\pi^- + P +$ short recoil, which is consistent with either $_\Lambda He^4$ or $_\Lambda He^5$. The measured velocity of A ($\beta = 0.26 \pm 0.02$ from ionization) and the requirement of energy conservation exclude the direct production of B by a stable particle A. These same kinematic data together with a scattering measurement on track A also exclude production of B by interaction of K^-, Σ^+, or Ξ^-. M_A from scattering vs ionization is $3.3 \pm 1.1 M_p$. Energy and momentum can be balanced if this event represents either of the reactions:

(1) charge exchange, $_\Lambda H^4 + (Z,A) \rightarrow {}_\Lambda He^4 + (Z-1, A)$ or

(2) proton pickup, $_\Lambda H^4 + (Z,A) \rightarrow {}_\Lambda He^4 + (Z-1, A-1)$,

while the possibility that A is due to a new ultra-heavy hyperon cannot be excluded.

* Supported by the Greenewalt Nuclear Physics Fund, the Office of Naval Research, and the U. S. Atomic Energy Commission.
† On leave of absence from the University of Milan.

Y4. Photoproduction of K^+ Mesons.* A. B. Clegg, M. P. Ernstene, and A. V. Tollestrup, *California Institute of Technology.*—The photoproduction of K^+ mesons from polyethylene targets has been observed with the Caltech synchrotron operating at energies between 1.1 and 1.2 Bev. The particles were required to traverse two "dE/dR counters," which were 1-cm thick scintillators, and to stop in a one-inch thick "ΔR counter." Upper and lower biases were set to eliminate both protons and π mesons in the two "dE/dR counters". The two dE/dR counters were necessary to eliminate the π mesons since their pulse-height spectrum is broadened by Landau effect. A proper coincidence triggered an oscilloscope on which the pulse from the ΔR counter was displayed and photographed. The time resolution for the photographed pulses was 10 $m\mu$ sec. K^+ mesons are identified by the size of their decay pulse and by the half-life of the decay spectrum. The efficiency of the experimental arrangement is being calculated and cross sections will be presented.

* This work was supported in part by the U. S. Atomic Energy Commission.

Y5. Nuclear Emulsion Detection of Photo-Produced K Particles.* V. Z. Peterson, C. E. Roos, and T. C. Terman, *California Institute of Technology.*—The photoproduction of positive K particles by 1100-Mev bremsstrahlung has been observed by stopping magnetically selected particles in nuclear emulsion detectors. The cross section for associated production, and the distribution of decay modes for photo K's (as compared with nucleon-produced K's) are being studied. Positive particles emitted from a carbon target at a mean laboratory angle of 42° in the momentum interval 250 to 300 Mev/c are selected by a bending magnet and then focused on an emulsion pellicle stack by a quadrupole lens. Range separation of particles of different mass is used; protons stop within the first cm of emulsion, K's stop between 2.5 and 4.0 cm, and pions and electrons pass completely through the 4-in. deep stack with near minimum ionization. The K's found so far have been located by area scanning single plates; with the complete stack it will be possible to line-scan the region beyond the maximum proton range for tracks of 3 to 6×minimum grain density. The background, which is very low, consists chiefly of products of pion interactions in the emulsion.

* This work was supported in part by the U. S. Atomic Energy Commission.

Y6. Photoproduction of K^+ Mesons in Polyethylene.* P. L. Donoho and R. L. Walker, *California Institute of Technology.*—K^+ mesons produced in a polyethylene target by the 1100- to 1200-Mev bremsstrahlung beam of the Caltech synchrotron, have been observed by means of a magnetic spectrometer and several scintillation counters. K^+ mesons, presumably from the reaction $\gamma + P \rightarrow K^+ + \Lambda^0$, were observed at a laboratory angle of 35° and momentum 440 Mev/c. These particles were identified by means of momentum selection in the magnetic spectrometer, time of flight, and an analysis of the pulse heights in three counters placed near the spectrometer focus. We obtain a yield from a 1-in. thick polyethylene target of 4.3×10^{-30} K^+ mesons per sterad per Mev per Q. If one assumes the above reaction and neglects all effects of binding of the protons in the carbon nuclei, one obtains a cross section per proton of $\sigma(\theta) = 1.3 \times 10^{-31}$ cm²/sterad at a photon energy of 1060 Mev. The above preliminary numbers are based on a total of about 50 K^+ counts, but they are accurate only to perhaps a factor of 2 because a calibration of the beam monitor has not yet been made. Further measurements with a liquid hydrogen target will be carried out in the near future.

* This work was supported in part by the U. S. Atomic Energy Commission.

Y7. Σ^- Nuclear Reactions.* Walter H. Barkas and Conrad J. Mason, *University of California, Berkeley.*—As part of a program of K^--meson research[1] we have studied Σ^- capture by nuclei. The reaction $Z^A[\Sigma^-, \Lambda^0](Z-1)^A$, which has an energy release of 70 to 80 Mev, is the dominant process for star formation by Σ^- hyperons stopping in emulsion. The elementary reaction $p(\Sigma^-, \Lambda^0)n$ divides the available energy between the Λ^0, the neutron, and the residual nucleus. Depending on whether the Λ^0 and neutron escape or not, and

whether the nucleus is light or heavy, different emulsion star types are seen. In the Ag, Br group escape of the Λ^0 is likely to be accompanied only by neutron emission, whereas capture of the Λ^0 should give π^--type stars. The C, N, O group of nuclei usually disintegrate, yielding charged-particle stars, often of low energy. If the Λ^0 is captured in a light element one prong is a hyperfragment. As indicated by the presence of low-energy prongs, at least 70% of the stars are from light elements, and of these 1/5 contain hyperfragments. Charged-pion emission is rare. The average visible energy release from light-element stars in about 23 Mev. At least 30% of the Σ^- capture events do *not* lead to charged-particle emission.

* This work was done under the auspices of the U. S. Atomic Energy Commission.
[1] Barkas, Dudziak, Giles, Heckman, Inman, Mason, Nickols, and Smith, UCRL-3627 (December, 1956) and Phys. Rev. (to be published).

Y8. The K^0 Meson as a Particle Mixture.* WILLIAM B. FOWLER, RICHARD LANDER, AND WILSON M. POWELL, *University of California, Berkeley.*—A beam of 1.25-Bev/c π^- mesons struck a 4×4×12 in. Al producer. The pictures analyzed correspond to a total flux of 2×10^5 mesons. Neutral particles emitted at 5° traveled 9.3 ft to a 3.25×6×12 in. propane bubble chamber in a 12 000-gauss magnetic field.[1] The π mesons were swept out by an intervening magnet. Of 46 two-prong events with a negative prong consistent (by bubble count and momentum) with a π meson and a positive prong consistent with proton, 17 had a $Q(p,\pi^-)$ consistent with 37 Mev. At least ten of these are thought to be Λ^0 decays. One originates from a two-prong star in the propane, the rest probably from the 2-in.-thick steel walls. Forty events with negative and positive prong each consistent with a pion or an electron show $Q(\pi,\pi)$ values consistent with the θ_1^0 in eleven cases; three of these originate in the propane. Negative electrons have been identified in three of the remaining 29 events, and the negative particles in five others are believed to be electrons. The background of $n+n\rightarrow p+\pi^-+n$ from carbon in the propane will be discussed.

* This work was done under the auspices of the U. S. Atomic Energy Commission.
[1] Lander, Fowler, and Powell, Bull. Am. Phys. Soc, Ser. II, 1, 385 (1956).

Y9. Report on Long-Lived Neutral K Mesons.* K. LANDE AND L. M. LEDERMAN, *Columbia University*, AND W. CHINOWSKY, *Brookhaven National Laboratory.*—In the continuation of an experiment previously reported[1] we have accumulated over 100 decays of neutral V particles whose flight paths from production to the 36-in. diameter expansion cloud chamber require $\sim3\times10^{-8}$ sec. Evidence will be presented strengthening the conclusion that these are K-mass particles which disintegrate primarily via the neutral counterpart of the $K_{\mu2}^+$ and $K_{\pi2}^+$ decay modes. Evidence for the $K_{\pi2}^+$ neutral counterpart (τ^0) will also be given. Angular and energy distributions for those events which are identified by ionization measurements or kinematical analysis will be displayed. An interaction in the gas which produces a negative unstable particle (probably a Σ^-) demonstrates with high probability the time dependence of the strangeness quantum number in the neutral K beam as predicted by the particle mixture theory.

* This research was supported in part by the U. S. Atomic Energy Commission and the Office of Naval Research.
[1] Lande, Booth, Impeduglia, Lederman, and Chinowsky, Phys. Rev. **103**, 1901 (1956).

Y10. Neutral Decay Mode of the θ^0.* H. BLUMENFELD, E. BOLDT, H. S. BRIDGE, D. O. CALDWELL, AND Y. PAL, *MIT.*—If the spin and parity of the θ^0 are even, the decay mode $\theta^0\rightarrow2\pi^0$ is allowed, whereas if the spin and parity are odd, it is forbidden. In the former case, if also the total isotopic spin selection rule for decay, $\Delta T=\frac{1}{2}$, holds, the ratio $\theta^0\rightarrow2\pi^0/\theta^0\rightarrow\pi^+\pi^-$ should be $\frac{1}{2}$. We have looked for $\theta^0\rightarrow2\pi^0$ decays among the unstable particles produced by 1.8-Bev π^- mesons (from the Brookhaven Cosmotron) in a large multiplate cloud chamber. The chamber has 17, $\frac{1}{8}$-in. iron plates and a well-illuminated region of about $1\frac{1}{2}$ ft×$3\frac{1}{2}$ ft×4 ft, and hence is an efficient shower detector. In about 800 unstable particle decays found so far, we have seen showers attributable to $\Sigma^0\rightarrow\Lambda^0+\gamma$, $\Sigma^+\rightarrow p+\pi^0$, and probably $\Lambda^0\rightarrow n+\pi^0$. We have searched for the $\theta^0\rightarrow2\pi^0$ particularly by looking for suitable showers associated with identified Λ^0's. From the lack of such showers we can conclude that if the $2\pi^0$ decay exists, the ratio $2\pi^0/\pi^+\pi^-$ is certainly less than $\frac{1}{2}$. An upper limit for this ratio will be given.

* Supported in part by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.

Y11. Study of τ^+ Meson Decays in a Propane Bubble Chamber.* T. F. ZIPF AND M. L. PERL, *University of Michigan.*—The scattering of positive K mesons has been observed in the University of Michigan propane bubble chamber at the Brookhaven Cosmotron.[1] Included in the pictures are over a hundred positive τ mesons which stop and decay in a region of the chamber such that all decay configurations may be identified with a high efficiency. Measurements on these decays provide the energy spectrum of the negative π meson with accuracy comparable to that attained by the emulsion technique. The fact that such events may be found and measured in a bubble chamber in much less time than in an emulsion shows that a hydrocarbon bubble chamber is an efficient means of substantially improving the statistics in this case. Experimental results of the analysis of the τ-meson decay will be presented.

* Supported in part by the U. S. Atomic Energy Commission.
[1] Meyer, Perl, and Glaser, Bull. Am. Phys. Soc, Ser. II, 1, 385 (1956).

Y12. Observation of a $\tau^{+\prime}$ Decay Involving a "Dalitz" Pair.* W. SLATER AND R. SETTI-LEVI,† *University of Chicago.*—A heavy meson from a 4.5-Bev π^- star in emulsion comes to rest and decays into a ~10-Mev π^+ (identified by π-μ-e) and two electron tracks. Momentum cannot be conserved among the visible particles only. The low energy of the π^+ rules out the $K_{\pi2}$ decay mode. Assuming that the electron pair is due to the decay $\pi^0\rightarrow\gamma+e^++e^-$ (Dalitz' internal conversion), this event gives supporting evidence for the generally assumed decay mode $\tau'^+\rightarrow\pi^++2\pi^0$. Measurements are in progress and a detailed discussion of this event will be presented.

* Work supported by the U. S. Atomic Energy Commission, the Office of Naval Research, and the Greenewalt Nuclear Physics Fund.
† On leave of absence from the University of Milan.

Y13. Angular Distribution of K^+ Meson Decay Products. E. BYERLY BRUCKER,* *The Johns Hopkins University*, AND GIOVANNI FAZIO,† *MIT.*—On the chance that the K^+ meson has spin greater than zero and is polarized when it is brought to rest in a stack of nuclear emulsions, several hundred stopped K_L mesons have been analyzed to detect an asymmetry of the charged particle decay. Preliminary analysis by octants shows no evidence for an asymmetry. However, detailed angular distributions are now being plotted and will be presented. Lack of asymmetry could be caused by any of several reasons which will be discussed. In addition, the angular distribution for 50 events definitely established as $K_{\mu2}$ will be presented.

* Supported in part by the U. S. Air Force through the Air Force Office of Scientific Research of the Air Research and Development Command.
† Assisted by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.

Y14. Charged Hyperon Decay in Emulsion.* PETER C. GILES, *University of California, Berkeley.*—The study of hyperons produced by an enriched beam[1] of K^- mesons has been extended to a large emulsion stack exposed to the particles. To date 71 hyperon decays from 450 one- and two-prong K^- stars have been analyzed. From Σ^+ hyperons decaying at rest to protons, we obtain a Σ^+ mass of $2328.0\pm0.7m_e$.

From K^- interactions at rest with hydrogen, yielding charged hyperons of both signs, we obtain a Σ^- mass of $2340.8\pm1.8m_e$. The Σ^+ lifetime, obtained from the $\Sigma^+\rightarrow p+\pi^0$ mode of decay alone, is 1.00×10^{-10} sec, based on 11 decays in flight. The energy distributions of charged hyperons emitted from one-prong and from two-prong stars will be given as well as their decay angular distributions.

* This work was performed under the auspices of the U. S. Atomic Energy Commission.

[1] Barkas, Dudziak, Giles, Heckman, Inman, Mason, Nickols, and Smith, UCRL-3627 (December, 1956), and Phys. Rev. (to be published).

SATURDAY AFTERNOON AT 1:30

NBS, East Building

(L. R. MAXWELL presiding)

Magnetism

Z1. Force-Free Magnetic Field Configurations. H. P. FURTH, *U.C.R.L., Livermore,* M. A. LEVINE, *C.A.F.R.C., Boston,* AND R. W. WANIEK, *Harvard University.*—Since the magnitude of the magnetic stress tensor puts an inherent limit on the field strength that can be achieved in the self-distending coils of conventional design, it is of interest to consider generalized coils exerting no self-force.[1] The existence of force-free configurations on a galactic scale has been hypothesized by astrophysicists,[2,3] and mathematical solutions to the equation $\nabla\times H=\alpha H$ have been derived for α a constant. By generalizing α, it is possible to design force-free and partially force-free coils of practical construction and applicability in the laboratory. Since force-free coils will generally be many-layer structures the Joule heating associated with the magnetic field can be so distributed as to avoid high local temperatures. A number of theroretical and experimental models will be discussed. Previously observed phenomena in gaseous discharges will be also interpreted in terms of force-free configurations.[4,5]

[1] Furth, Levine, and Waniek, Bull. Am. Phys. Soc. Ser. II, **1**, 7 (1957).
[2] R. Luest and A. Schlueter, Z. Astrophys. **34**, 263 (1954).
[3] S. Chandrasekhar, Proc. Natl. Acad. Sci. **42**, 1 (1956).
[4] M. A. Levine and L. S. Combes, Tufts College Rept. 16 (1954).
[5] W. H. Bostick, Phys. Rev. **104**, 292 (1956).

Z2. Application of the Vibrating Sample Magnetometer to Weakly Magnetic Materials.* SIMON FONER, *Lincoln Laboratory.*—The sensitivity of the vibrating sample magnetometer described earlier[1] has been extended to measure magnetic properties of weakly magnetic materials. The principle of operation is based on detection of the oscillatory dipole field produced by a sample vibrated perpendicular to a uniform magnetizing field. A suitable arrangement of two detection coils and a null detection system permits accurate magnetization measurements as a function of temperature, crystal orientation, and field to be made independent of sample position, vibration amplitude, or amplifier gain. Using suitable electronics, a susceptibility of 10^{-9} cgs units per gram is detectable for a one-gram sample and a magnetizing field of 10 kilogauss. Detailed performance characteristics of a double coil system—also a single coil arrangement following higher magnetizing fields—and applications to ferromagnetic, paramagnetic, diamagnetic, and antiferromagnetic materials will be presented. Possibilities of improving sensitivity even further, accurate calibration, and present limitations of the vibrating sample magnetometer are considered and compared with other methods.

* The research reported in this document was supported jointly by the U. S. Army, Navy, and Air Force under contract with MIT.
[1] S. Foner, Rev. Sci. Instr. **27**, 548 (1956).

Z3. Low-Temperature Anomalous Magnetization of Uranium Dioxide. WARREN E. HENRY, *U. S. Naval Research Laboratory.*—Magnetization studies on uranium dioxide have been carried out down to liquid helium temperatures, using a sample motion technique. As the temperature is lowered from 300°K, there is a sluggish increase in the constant field magnetization, in good accord with susceptibility measurements[1] above 90°K. Whereas the high-temperature susceptibility indicates an intrinsic moment of over 3 Bohr magnetons per uranium atom (suggestive of a $5f^2$ or $5f^16d^1$ configuration for a $^3H_4$ ground state[2]), the magnetization in the liquid helium range is inordinately low (0.02 Bohr magneton per atom of uranium at 35 000 gauss) and temperature is independent. The measured moment can be formally computed from the quantity $C/(T+\Delta)$, where Δ is of the order of 200°K. Although antiferromagnetic exchange interaction is indicated by the low-temperature magnetization reported here, by the specific heat maximum,[2] and by neutron diffraction[3] studies, one should also consider the possibility of a reduction in the intrinsic moment for uranium in UO_2 through splitting by interaction similar to that in potassium ferricyanide.

[1] Dawson and Lister, J. Chem. Soc. (London) 2181 (1950).
[2] Jones, Gordon, and Long, J. Chem. Phys. **20**, 695 (1952).
[3] Henshaw and Brockhouse, Bull. Am. Phys. Soc. Ser. II, **2**, 9 (1957).

Z4. Theory of Ferromagnetic Anisotropy. W. J. CARR, JR., *Westinghouse Research Laboratories.*—By means of a virial-perturbation calculation, the anisotropy energy of a ferromagnetic crystal is expressed in terms of the Coulomb energy alone. This latter energy is approximated by a multipole expansion and the anisotropy constants are given in terms of electric multipole moments and crystalline potential constants. The multipole moments, which arise from the orbital angular momentum induced by spin-orbit coupling, have been estimated from the known values of angular momentum. The method avoids explicitly carrying out high-order perturbations and has been carried through without assuming phenomenological couplings or simplified one-electron models.

Z5. Exchange Effect Considerations in Ferromagnetic Resonance.* M. H. SEAVEY, JR., AND P. E. TANNENWALD, *Lincoln Laboratory.*—We have made an analysis of the effect of the exchange term $[(2A/M_s^2)\mathbf{M}\times\nabla^2\mathbf{M}]$ on ferromagnetic resonance for the case of the applied magnetic field parallel to the direction of propagation. Similar analyses plus experimental observations have been carried out previously[1,2] for the case of the field perpendicular to the direction of propagation. The treatment of the parallel case is less difficult than the perpendicular case, since two quadratic equations rather than one cubic must be solved for the propagation constants. Four normal modes of propagation (two positive rotating and two negative rotating circular modes) exist, and at least one of the two modes which arise from the exchange term appears to be significant and should have observable effects even at room temperature. The boundary value problem is solved, and the equivalent permeability[2] for exchange damping

only is plotted as a function of magnetic field. The electromagnetic problem for transmission through a thin film is solved, and the transmission for the case of exchange damping only is compared with that for relaxation damping only.

* The research reported in this document was supported jointly by the Army, Navy, and Air Force under contract with MIT.
[1] J. R. Macdonald, Ph.D. thesis, Oxford, 1950 (unpublished); Phys. Rev. **103**, 280 (1956).
[2] G. T. Rado and J. R. Weertman, Phys. Rev. **94**, 1386 (1954); W. S. Ament and G. T. Rado, Phys. Rev. **97**, 1558 (1955).

Z6. Shape of the Ferromagnetic Resonance Line in Polycrystalline Ferrites. E. SCHLÖMANN, *Raytheon Manufacturing Company.*—If the anisotropy field is much larger than the single crystal line width and the saturation magnetization, the shape of the resonance line is essentially determined by the spreading of resonance frequencies for different grains due to crystalline anisotropy. More precisely: If $w(H)dH$ is proportional to the number of grains that have their resonance in the range of applied dc field between H and $H+dH$, the absorption *versus* field curve should be a smeared out image of the distribution function $w(H)$. The distribution function has characteristic singularities arising from the stationary points of the resonance field *versus* orientation surface. The behavior of $w(H)$ in the vicinity of the singularities is calculated for first order cubic anisotropy and $w(H)$ is obtained by interpolation. For small anisotropy fields, the calculated line shape has a single peak which corresponds to grains in which a [110] direction is aligned with the dc field. For larger anisotropy fields ($\gamma H_a/\omega \gtrsim 0.5$) a secondary peak occurs. It corresponds to grains in which an easy axis is aligned with the dc field. The theory accounts for secondary resonance peaks at low fields observed in ferrites of small saturation magnetization.

Z7. Ferromagnetic Resonance in Polycrystalline $NiFe_{2-t}Al_tO_4$. J. R. ZEENDER AND E. SCHLÖMANN, *Raytheon Manufacturing Company.*—Measurements were made at X band for t between 0.6 and 1.0. Near the magnetic compensation point, the resonance line is very wide and has a shape similar to the one observed by McGuire[1] in $Li_{0.8}Fe_{1.25}Cr_{1.25}O_4$. Measurements between $-70°C$ and $360°C$ made on a sample with $t=0.65$ quenched from 1200°C gave the following results: At room temperature the line shows a main absorption peak and shoulders on each side. At higher temperatures, the line is narrower, the shoulders are less pronounced and finally disappear. At lower temperatures, the low field shoulder becomes the predominant absorption peak, and two shoulders are observed on the high field side. Similar results are obtained for different compositions and after quenching from different temperatures. The line shape is interpreted on the basis of the theory given in the preceding abstract. Reasonably good agreement is found between measured and calculated line shapes if it is assumed that the first-order cubic anisotropy constant is negative and that all higher order anisotropy constants are zero. The anisotropy fields $2|K_1|/M_s$ determined in this way are in the range of 800–1700 oersteds.

[1] T. R. McGuire, Phys. Rev. **97**, 831 (1955).

Z8. Exchange Anisotropy in Fe-FeO. W. H. MEIKLEJOHN, *General Electric Research Laboratory.*—Evidence of exchange anisotropy[1] has been found in the Fe-FeO system. Exchange anisotropy is the result of an interaction between a ferromagnetic and antiferromagnetic system. It is shown that the rotational hysteresis has a nonvanishing value at high fields [$H>(2K/I_s)$] for temperatures below the Néel temperature of FeO, and a zero value of rotational hysteresis for temperatures greater than the Néel temperature.

[1] W. H. Meiklejohn and C. P. Bean, Phys. Rev. **102**, 1413 (1956).

Z9. Optical Transparency and Faraday Rotation in Yttrium-Iron Garnet (YIG). J. F. DILLON, JR., *Bell Telephone Laboratories.*—It has been found that YIG crystals are transparent to visible light from long wavelengths to the green. Thin sections (e.g., 0.002 in. thick) transmit sufficient light for microscopic examination. Further it is found that the transmitted light is rotated in one sense if the magnetization is along the line of sight, the other sense if the magnetization is in the opposite direction. That is, it experiences a Faraday rotation of several degrees per mil. The specific rotation varies with wavelength. By virtue of this rotation, the domain structure of the crystals is readily apparent and can be studied over a wide variety of temperatures and applied field conditions. Most important, we now have access to spectroscopic information over a wide temperature range relating to levels well above the ground state. It may be that the observed rotation results from the spin-orbit splitting between the allowed optical transitions of trivalent iron.

$$3d^5\,{}^6S_{\frac{5}{2}} - 3d^4 4p\,{}^6P_{\frac{7}{2}} \quad \text{and} \quad 3d^5\,{}^6S_{\frac{5}{2}} - 3d^4 4p\,{}^6P_{\frac{5}{2}}.$$

Z10. Spin-Lattice Interaction in $Co_xFe_{3-x}O_4$. J. C. SLONCZEWSKI, *IBM Research Laboratory.*—A quantum-mechanical theory of spin-lattice interaction of Co^{2+} in octahedral coordination is developed. The molecular field approximation of the exchange interaction is used. The effects of the cubic crystalline field, crystalline fields of lower symmetry, and spontaneous displacement of nuclei from highly symmetric positions (Jahn-Teller effect) are considered. In the ferrite the octahedral sites are classified into four equivalent types, each type having approximately trigonal symmetry along a different body diagonal. For small x, under some assumptions, the cobalt spin is coupled uniaxially to the appropriate body diagonal and contributes anisotropically to the magnetocrystalline energy. This energy is calculated to the fourth order in the spin-orbit perturbation, and an estimate of the resulting cubic anisotropy is obtained. The degree of consistency between measured cubic anisotropy[1] and field-induced anisotropy[2] for a mobile cation model is considered. The deviation from body-diagonal interaction for large x is also considered.

[1] Bickford, Brownlow, and Penoyer, Paper R2188, Inst. Elec. Engrs. Convention on Ferrites (London, 1956).
[2] R. F. Penoyer and L. R. Bickford, Jr., Bull. Am. Phys. Soc. Ser. II, **2**, 21 (1957).

Z11. Magnetic Moment of $3Y_2O_3 \cdot xM_2O_3 \cdot (5-x)Fe_2O_3$ Garnet for M = Al, Sc, and Ga. M. A. GILLEO AND S. GELLER, *Bell Telephone Laboratories.*—In a ferrimagnetic yttrium-iron garnet[1,2] a portion, x, of iron may be replaced by a nonmagnetic ion M: $Y_3(Fe(a)_{1-y}M_y)_2(Fe(d)_{1-z}M_zO_4)_3$; the $Fe^{3+}(a)$ ions are in octahedral, the $Fe^{3+}(d)$ in tetrahedral sites. The magnetic moment initially varies as $5(1+2y-3z)$ Bohr magnetons per formula unit; $2y+3z=x$. For M = Al and Ga, $3z \simeq x$ (tetrahedral site preference); for M = Sc, $2y \simeq x$ (octahedral site preference). The garnet structure persists for M = Al and Ga up to complete replacement of iron ($x=5$), but has not been observed for total replacement by Sc.

[1] F. Bertaut and F. Forrat, Compt. rend. **242**, 382 (1956).
[2] S. Geller and M. A. Gilleo, Acta Cryst. **10**, (1957) (to be published).

Z12. Some Remarks on the Volume Magnetostriction and the ΔE Effect at High Fields above Magnetic Saturation. HIROSHI SATO, *Ford Motor Company.*—The total energy W of a ferromagnetic substance may formally be divided into three terms, W_1, W_2, and W_3, where W_1 is an energy term of nonmagnetic origin, W_2 is one coming from the existence of spontaneous magnetization, and W_3 is one which depends upon the direction of the magnetization relative to the crystallographic axes, i.e., the anisotropy energy. So far the volume magnetostriction at high fields is considered exclusively to come through the W_2 term. We have considered the dependence of the anisotropy energy on the degree of spin alignment and have shown how the W_3 term also gives rise to a forced magnetostriction including a volume effect. This will

explain the existence of an anisotropic forced magnetostriction. Similar arguments are applied to the elastic constants of ferromagnetic substances. From a detailed analysis of the energy terms given in the foregoing, we can understand the dependence of elastic constants upon the direction of magnetization at high fields.[1] Also the temperature dependence of elastic constants in the ferromagnetic range can be explained, from which we can also argue the nature of the interaction energy between magnetic moments.

[1] Neighbours, Alers, and Sato, Bull. Am. Phys. Soc., Ser. II, 2, 118 (1957).

Z13. Studies of a Monte Carlo Method Applied to the Ising Lattice Problem. L. D. Fosdick,* *Midwestern Universities Research Association.*—The two-dimensional Ising lattice is a simple statistical system with interesting and exactly known properties. It is thus an interesting test model for numerical procedures on similar, but more complex statistical systems. Accordingly, an investigation of the accuracy achievable in an application of a Monte Carlo method† to the two-dimensional Ising lattice problem has been made. The[1] dependence of the computed energy and magnetization on lattice size, number of iterations, and initial state of the system was observed. Computations were made for spin arrays of 10×10, 20×20, and 37×37. Away from the Curie point, errors of less than 1% were achieved with the 20×20 lattice, the larger lattice showing little improvement. The number of iterations varied up to 768 passes through the lattice. For the 20×20 lattice 100 passes appeared to bring the system to "equilibrium" except in the neighborhood of the Curie temperature where fluctuations caused erratic results. Initial spin configurations of complete order and complete disorder gave comparable results after approximately the same number of iterations. Computations were performed on the ILLIAC at the University of Illinois.

* Most of this work was done while the author was at the Control Systems Laboratory of the University of Illinois.
† Metropolis, Rosenbluth, Rosenbluth, Teller, and Teller, J. Chem. Phys. 21, 1087 (1953).

Z14. Effects of Defects on Spin Interactions in a Simple Cubic Lattice.* A. Ishihara, *University of Maryland.*—Effects of lattice defects such as foreign atoms or holes on spin-spin interactions in a simple cubic lattice are calculated by adopting the so-called spherical model. In the case when the concentration of defects is low and the distance between any pair of defects is large, the exact positions of defects are not important, and the excess free energy and other thermodynamical functions become functions of concentration of defects. Langevin-Curie's law of magnetic susceptibility is modified because of the presence of defects especially in the neighborhood of the ferromagnetic Curie point which is also determined by defects. The correlation between spins is also calculated.

* This research was partially supported by the U. S. Air Force.

Saturday Afternoon at 1:30

Sheraton-Park, Caribar-Mural Room

(V. Bargmann presiding)

Theoretical Physics V: Relativity and Quantum Mechanics

ZA1. New Clock Problems in Special Relativity Theory. R. Schlegel, *Michigan State University.*—Application of the Lorentz time transformation to a hypothetical clock regardless of its interaction situation leads, in addition to the well-known clock paradox, to three other problems. (1) Clock frequencies are required to decrease with relative motion, although the observed increase of mass with motion requires an increase in the frequency $\nu=mc^2/h$. (2) The reading of a given clock is presumably the same for observers in all coordinate systems, but the observables of confirmed relativistic processes vary with coordinate system. (3) Meson lifetimes are increased from τ_0 to τ by motion relative to counters (or atmospheric atoms) with which decay particles interact. A hypothetical clock moving with a meson must record a lifetime τ_0; yet, this meson interacts with counters moving with high relative velocity, and the clock at rest to it should therefore record the dilated lifetime τ. The clock difficulties may be removed by confining relativistic transformations to situations which involve high velocity physical interactions; clock rates are then generally the same in all inertial systems. Lorentz transformations applied directly to photon frequencies and wavelengths (and as confirmed in the Doppler effect) insure the invariance of light speed c. Further discussion will be published.

ZA2. Creation of Energy in an Expanding Universe. Winston H. Bostick, *Stevens Institute of Technology.*—A new model of the galaxy suggested by work with plasmoids[1] indicates that the primordial ingredients are protons and electrons which undergo gravitational contraction across a magnetic field of the galaxy's own making. It is reasonable to assume that these equal numbers of protons and electrons come from the decay of the neutron. We therefore look for a process whereby the neutron can be synthesized in free space. Models of the elementary particles have already been advanced[2] in which it is shown that the electromagnetic field can be stabilized in ring-shaped configurations by self-gravitational forces. It will be shown how these models can give the potential well of the deuteron and how they can exhibit diffraction and interference effects. The theory contains within it a place for photons, left- or right-handed screw-shaped neutrinos (already advanced),[2] and antimatter. The models suggest that the neutron is synthesized by the self-gravitational contraction of the electromagnetic field, and that the energy content of the universe can be zero.

[1] W. H. Bostick, Phys. Rev. **104**, 292 (1956); (also, to be published).
[2] W. H. Bostick, Phys. Rev. **100**, 1250(A) (1955).

ZA3. Equations of Motion in Gravitational Theory. J. N. Goldberg, *Aeronautical Research Laboratory.*—In order to look for effects of gravitational radiation, a weak field expansion for the gravitational potentials has been used which does not assume the velocities of the particles (singularities of the field) to be small compared with that of light. Instead of the surface integral conditions employed by Einstein and Infeld[1] to obtain the equations of motion for the particles, we require that the energy-momentum tensor satisfy the Bianchi identities across the singularities. This method has previously been employed by Infeld in the case of slow motion.[2] In the case of fast motion this procedure permits one to obtain the equations of motion in the $(n+1)$th order when the field equations have been solved to the nth order. In the first order there is no

interaction between particles and we choose retarded Liénard-Wiechert potentials as solutions for the field equations. The equations of motion in the second order are then obtained as described above. No radiation damping term appears in this order.

[1] A. Einstein and L. Infeld, Can. J. Math **1**, 209 (1949).
[2] L. Infeld, Acta Phys. Polon. **13**, 187 (1954).

ZA4. Two-Component Spinors in General Relativity.* PETER G. BERGMANN, *Syracuse University*.—Originally, H. Weyl related two-component spinors to a general Riemannian metric through quadrupoles, thus introducing local Lorentz transformations. As an alternative procedure, we shall formulate the basic algebraic relationships in a direct covariant manner without reference to quadruples. In this formalism the groups of coordinate transformations in four-space and of unimodular transformations in the 2×2 spin space are unrelated to each other. It is possible to introduce spin-affine connections and, with their help, to construct a spin-curvature tensor. The latter is simply related to the usual Riemann-Christoffel tensor of Riemannian geometry.

* Supported by the Air Force Office of Scientific Research.

ZA5. Electrodynamics of Material Media in General Relativity.* JOHN ISE, JR., *University of California, Berkeley*.—The equations for the electromagnetic field in rotating material media are derived from the covariant tensor formulation of classical general relativity and applied to a few simple problems. The radial electric field (in the laboratory system) inside a rotating magnetic insulator is shown to be (in mks units)

$$E_r=-\omega r B_z\left\{1-\frac{1}{c^2\left[\mu K\epsilon_0+\gamma^2\beta^2\left(\mu K\epsilon_0-\frac{1}{c^2}\right)\right]}\right\}$$

(where $\beta=\omega r/c$, $1/\gamma^2=1-\beta^2$), compared to that derived from the Lorentz transformation of special relativity,

$$E_r=-\omega r B_z[1-(1/\epsilon_0 K\mu c^2)].$$

The electrostatic field outside a spinning magnet is shown to be zero, and the invariance of the magnetic field in rotating systems will be discussed.

* This work was performed under the auspices of the U. S. Atomic Energy Commission.

ZA6. Synthesis of Charged-Particle Trajectories. WILLIAM E. WATERS, JR., AND DON MITTLEMAN, *Diamond Ordnance Fuze Laboratories*.—The problem of determining the Laplacian (electrostatic) potential distribution within which a charged particle may be made to follow a specific path with specified velocity at each point on the path, may be reduced to a boundary-value problem in electrostatics. The potential V at each point may be calculated from the energy equation, $mv^2=-2e(V+V_0)$; this expression may be differentiated to obtain the tangential component of electric field, E_t. Upon equating the centrifugal force to the electric force, the normal component of field is found to be given by $\mathbf{E}_n=-2V\mathbf{K}$, where $\mathbf{K}$ is the vector curvature. Hence, at each point on the desired path the potential and total electric field may be determined. These constitute the boundary conditions on the Laplacian function. Examples will be given of the use of this technique to predetermine charged-particle paths. Methods for actually solving the boundary-value problem will be briefly discused.

ZA7. Derivation of the Corrected Bohr-Sommerfeld Quantum for Nonseparable Systems.* JOSEPH B. KELLER, *New York University*.—The Bohr-Sommerfeld quantum conditions are deduced from quantum mechanics, without recourse to separation of variables, in the limit as h approaches zero. Thus the conditions are obtained in the general form due to Einstein, which is applicable to nonseparable classical systems, rather than in the special form due to Sommerfeld, which applies only to separable systems. Our formulation also resolves uniquely the ambiguity as to whether an integer or half-integer quantum number is to be used. Previous derivations have applied only to separable quantum mechanical systems. The present derivation is based on an extension of the WKB method to partial differential equations, used by Dirac and others. By this method an asymptotic solution of the Schroedinger equation is constructed from which the quantum conditions follow. In addition, the asymptotic solution itself may prove to be useful.

* Joseph B. Keller, Derivation of the Bohr-Sommerfeld quantum conditions from an asymptotic solution of the Shroedinger equation, Research Report, No. CX-10, Institute of Mathematical Sciences, New York University.

ZA8. Bound State Problems in the Classical Limit. S. I. RUBINOW, *Stevens Institute of Technology*, AND JOSEPH B. KELLER, *New York University*.—A method has been devised previously for the asymptotic solution of the Schroedinger equation in the classical limit and for the derivation of the Bohr-Sommerfeld quantum conditions (see preceding abstract). That method does not depend upon separation of variables. We have extended it to boundary value problems such as that of the motion of a particle in a box. Formulas for the eigenvalues and eigenfunctions have been obtained which involve a construction based upon classical trajectories. For the particle in a box those trajectories are rays which obey the optical law of reflection at the walls. Families of rays and their caustics play an essential role in the procedure. Particular applications have been made to boxes whose shapes are rectangular, circular, elliptic, parabolic, spherical, etc. In all these cases the results agree with those obtained asymptotically from the exact solution given by separation of variables. Certain new results, such as asymptotic formulas for Mathieu and associated Legendre functions have also been discovered.

ZA9. Calculation of the Scattering Potential for the One-Dimensional Dirac Equation from the Reflection Coefficient and Point Eigenvalues.* I. KAY AND H. E. MOSES, *New York University*.—The abstract formulation of the Gelfand-Levitan equation given by Kay and Moses[1] has been applied to the one-dimensional Dirac equation ($-\infty<x<\infty$) in order to find the scattering potential from appropriately defined reflection coefficients and point eigenvalues. The scattering potentials are taken to be 4×4 Hermitian matrices whose elements are functions of x. (The electromagnetic potentials are special cases of these potentials.) This problem is particularly interesting because it provides a simple analog to scattering in two or more dimensions, in which the x variable is one dimension and the spinor variable corresponds to the others.

* The research reported in this article has been sponsored by the Geophysics Research Directorate, A. F. Cambridge Research Center Command.
[1] I. Kay and H. E. Moses, Nuovo cimento, Ser. X, **2**, 917 (1955); *ibid.*, **3**, 66 (1955); *ibid.*, **3**, 276 (1955).

ZA10. Extension of the Rayleigh-Ritz Principle.* FRANCIS R. HALPERN, *University of California, Berkeley*.—The Rayleigh-Ritz principle for a quantum mechanical system governed by a Hamiltonian H sets forth, that, for an arbitrary state vector ϕ, the solution E of the linear equation $(\phi|\phi)E-(\phi|H|\phi)=0$ is greater than the smallest eigenvalue of H. There exists a polynomial of degree n in E such that all its roots are real and distinct, and lie between the greatest and least eigenvalues of H. Between any two roots of a polynomial there is one and only one root of the polynomial of degree one less. The coefficients of the polynomial are determinants whose elements are the matrix elements of the powers of H.

* This work was done under the auspices of the U. S. Atomic Energy Commission.

SUPPLEMENTARY PROGRAMME

SP1. Magnetic Analysis of Long-Range Particles from Fission of Uranium-235. CLYDE B. FULMER AND BERNARD L. COHEN,* *Oak Ridge National Laboratory.*—The long-range particles from pile neutron fission of uranium-235 have been studied with the high resolution magnetic spectrograph previously described.[1] The particles were detected by a scintillation arrangement using a CsI(Tl) crystal. The particles were verified to be alpha particles by comparing the scintillation pulse height as a function of HR with that of polonium-210 alphas and by range-energy measurements in aluminum. The energy distribution was determined, and good agreement was obtained with previous determinations[2,3] by other methods. An extensive search revealed no fine structure in the energy distribution. The shape of the energy distribution indicates that the particles are emitted at the instant of fission.

* To be given at the end of Session K if the Chairman rules that there is time.

[1] Cohen, Cohen, and Coley, Phys. Rev. **104**, 1046 (1956).
[2] K. W. Allen and J. T. Dewan, Phys. Rev. **80**, 181 (1950).
[3] E. W. Titterton, Proc. Roy. Soc. (London) **168**, 590 (1951).

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Seeman, N.—T14
Segel, Ralph E.—V3
Segrè, E.—H11, H12, H13
Sellen, J. M.—B4, J8
Sens, J. C.—M4, M5, M6
Seth, K. K.—TA13
Setti-Levi, R.—Y12
Shapiro, A. M.—M7
Shapiro, M. M.—DA3
Sharp, R. D.—D13
Shaw, H. C.—E10
Shields, Howard—U12
Shine, W. W.—UA2
Shirane, G.—SA3
Shockley, W.—L10
Shore, F. J.—S13
Shugart, H. A.—KA11
Siegel, Armand—LA4
Siegel, Benjamin M.—C2
Siegel, R. T.—J13
Signell, P. S.—CA4
Silsbee, H. B.—KA11
Silver, A. H.—U1
Singer, S. F.—DA2, H7
Singh, R. P.—L4
Simpson, J. A.—C6, DA4, H5
Simpson, O. D.—S12
Sirlin, A.—GA9
Skaggs, L. S.—C1
Slater, W.—Y3, Y12
Slattery, J. H.—E3
Slaughter, G. G.—S9
Slonczewski, J. C.—Z10
Slutsky, L. J.—R5
Smith, L.—G1
Smith, Lincoln G.—TA2
Smith, R. K.—K4, K14
Smith, W. R.—RA5
Smither, Robert K.—W6
Snow, G. A.—T14
Snowdon, S. C.—X8
Snyder, D. D.—R8
Solmitz, F. T.—T10
Solow, M.—A2
Spees, A. H.—F4
Sperduto, A.—D12
Springer, T. E.—S10
Stähelin, P.—G4, G7
Stapp, Henry P.—P12
Starr, W. L.—RA6
Steffen, R. M.—W1
Steinberger, J.—T4
Steiner, H.—H11, H12, H13
Stelson, P. H.—P1
Stern, Edward A.—R3, R4
Sternheimer, R. M.—CA6
Stewart, A. T.—L3
Stewart, John W.—FA12
St. Lorant, S. J.—M10
Stokes, R. H.—P3, P4, P5
Strandberg, M. W. P.—FA9, QA2, QA3, U9
Strauch, K.—M7
Street, J. C.—M7
Striebel, H. R.—X12
Stroke, H. H.—UA8
Stump, R.—B8
Swanson, R. A.—M4, M5, M6
Swenson, Donald A.—E1, E2
Symon, Keith R.—G12
Szepesi, Z.—FA6

Tagliaferri, G.—T6
Tannenwald, P. E.—Z5
Taylor, S.—T3
Teem, J. M.—C9
Telegdi, V. L.—M4, M5, M6, N4
Templeton, L. C.—FA5
Terman, T. C.—Y5
Terwilliger, Kent M.—G9, G10
Thomas, D. G.—A11, FA1
Thomas, G. E.—K3
Thomsen, John S.—LA1
Thorndike, A. M.—T8
Toll, John S.—CA10
Tollestrup, A. V.—Y4
Tomkins, F. S.—K13
Tomboulian, D. H.—KA1, KA2
Townes, C. H.—SA8
Treiman, S. B.—T5
Tripp, R. D.—T10
True, William W.—UA6
Turner, C. M.—G2

Ulrich, J. P.—D2
Umezawa, H.—GA6
Unterleitner, F.—SA3

Vacher, H. C.—L12
Vali, V.—RA6
Van Atta, C. M.—G1
Van der Leun, C.—D9
Vander Velde, J. C.—T1
van Rossum, Lud—T11
Vegors, Stanley H., Jr.—W7
Violet, C. E.—T12
Vreeland, John A.—TA9

Waddell, C. N.—E10
Wagner, F., Jr.—V1
Wagner, M. D.—C6
Walker, R. L.—Y6
Wall, N. S.—D4, E11, P8
Walters, G. K.—F7
Waniek, R. W.—Z1
Wang, T. C.—Q1
Warren, B.—K14
Warren, J. B.—D3
Waters, John R.—J6
Waters, William E., Jr.—ZA6
Watson, W. W.—Q5
Weaner, D. H.—D11
Weber, A. H.—L11
Weil, J.—E13
Weingart, R.—H13
Weinrich, M.—M1, M2
Welber, Benjamin—F3
Werbrouck, A.—T6
Wertz, John E.—FA2
West, H. I.—W5
Weston, L.—S6
Weyl, Peter K.—RA1
Wheelon, Albert D.—Q3, Q13
White, R. S.—T12
White, R. S.—T12
Whittemore, W. L.—T8
Wilets, Lawrence—UA3
Williamson, R. M.—C5
Williamson, R. M.—E15
Williams, Dudley—QA5, U3
Williams, R. W.—M7
Wiegand, C.—H11, H12, H13
Willis, C.—FA11
Wilson, R. R.—J7
Winick, H.—J12
Winkler, E. H.—RA10
Witmer, Enos E.—TA6
Wittry, David B.—R1
Wood, G. T.—C1
Woods, R. D.—L7
Wooten, B. A.—J12
Woodward, W. M.—J7
Wolfenstein, L.—GA8
Wolicki, E. A.—E7, E9
Wolga, G. J.—FA9
Wong, C.—X6, X7
Wong, David Y.—CA11
Worcester, J. L.—KA10
Wright, I. F.—E6
Wright, S. C.—M4, M5, M6
Wright, William R.—U8
Wu, C. S.—N2

Yahia, J.—F9
Yevick, G. J.—LA8, LA9
Young, L. A.—M7
Yovanovitch, D. D.—M4, M5, M6
Ypsilantis, T.—H11, H12, H13

Zeender, J. R.—Z7
Zemach, Charles—GA1
Ziegler, N. F.—G5
Ziering, S.—LA3
Zimmerman, R. L.—S1, S4, TA13
Zipf, T. F.—Y11
Zobel, W.—K9, K10, K11
Zumino, B.—GA7

Preliminary Announcement of the 1957 Summer Meeting in the East

The 1957 Summer Meeting of the American Physical Society in the East will be held on Thursday, Friday, and Saturday, June 20, 21, and 22, in the buildings of the University of Notre Dame at Notre Dame, Indiana. For our Division of Electron Physics this will be the principal meeting of the year, and the Division will largely determine the symposia and the invited papers. The Local Committee notifies us that dormitory accommodations will be available on the campus at $2 for singles and $3 for doubles: write to Professor J. W. Mihelich, Department of Physics, University of Notre Dame, Notre Dame, Indiana. On the campus there is a hotel, the Morris Inn (singles $9 to $12, doubles $12 to $19). In the neighboring city of South Bend there are the Hoffmann Hotel, the LaSalle Hotel, and the Oliver Hotel, all with somewhat lower rates, and a number of motels. South Bend is on the New York Central (the Canadian National Railways also send trains over its tracks) and the "South Shore" (Chicago, South Shore and South Bend) electric trains from Randolph Street, Van Buren Street and Central station in Chicago.

Deadline is to be Friday, April 12: abstracts are to be sent to the office of the Society at Columbia University, New York 27, New York.

Preliminary Announcement of the 1957 Summer Meeting in the West

The 1957 Summer Meeting of the American Physical Society in the West will be held on Thursday, Friday, and Saturday, September 5, 6, and 7, in the buildings of the University of Colorado at Boulder, Colorado. It is hoped that this may be a joint meeting with the Sociedad Mexicana de Física and perhaps also with the Canadian Association of Physicists. Further information will be given in the June issue of this Bulletin. Deadline is to be Monday, July 8, and abstracts are to be sent to the Local Secretary for the Pacific Coast (Professor W. A. Nierenberg, University of California, Berkeley 4, California).

Appeal to Professors

Professors and their secretaries in colleges and universities are asked to destroy whatever copies of the old nomination form (of nomination to membership in the Society) may still be lying around and to replenish their stocks by writing to the office of the Society for copies of the new form. By "the new form" is meant the one on the back of which a special place is provided for the signatures of sponsors who wish to claim the "student concession" for their candidates. By "the old form" is meant any form on which there is no allusion to the student concession. Many who have used the old form have forgotten that the student concession is not granted to those candidates who simply describe themselves as students on their forms. When the old form is used and the concession is desired, the form must be mailed to the office of the Society together with a separate letter in which one of the sponsors attests over his signature that the candidate is a full-time student regularly enrolled in an educational institution.

Be it recalled that the student concession consists in a reduction of dues from $15 to $10, plus the privilege of receiving one journal without additional payment. It lasts for only one year, and this must be the first year of the student's membership in the Society.

MEETINGS AND DEADLINES FOR THE REMAINDER OF 1957

Place	*Meeting dates*	*Deadline date*
Washington, D. C.	April 25–27	past
Notre Dame, Indiana	June 20–22	April 12
Boulder,* Colorado	September 5–7	July 8
St. Louis	November 29–30	September 27
Stanford,* California	December 18–21	to be decided

* Abstracts for the Boulder and Stanford meetings are to be sent to W. A. NIERENBERG, University of California, Berkeley 4, California, and must reach his office not later than the corresponding deadline date.

Abstracts for the other meetings listed above are to be sent to KARL K. DARROW, American Physical Society, Columbia University, New York 27, New York, and must reach his office not later than the corresponding deadline date. Take note that abstracts mailed the day before deadline-day often fail to arrive in time: the last postal delivery of the day usually comes to our office before 2 P.M. Allow at least two days for abstracts sent by airmail from points east of the Mississippi, and longer for those sent from farther west. To avoid chance of confusion, please do not send an abstract for any meeting until the deadline date of the previous meeting is at least five days past. *The privilege of contributing papers to meetings of the American Physical Society is restricted to the members of the Society and to nonmembers whose papers are sponsored by members.*

RULES AND INSTRUCTIONS FOR THE PREPARATION OF ABSTRACTS

The Council has ordered that abstracts shall be not longer than two hundred (200) words or the equivalent thereof. In reckoning equivalence, a footnote is equated to ten words; each line in a table to ten words; a "display" formula—one that requires a line to itself—is an expensive luxury equated to forty words.

Two copies of each abstract must be sent to the appropriate office. They must be typewritten; one must be an original, the other may be an original or a carbon copy. *They must be double-spaced:* single-spaced manuscripts are too crowded to permit the editorial markings to be made with ease and clearness. Each abstract must be confined to a single page: if it is too long for a single page it is too long to be printed. *If we receive an abstract typed on two pages, we print only its first page;* an example appears in this *Bulletin*. Write each abstract as a single paragraph: the suppression of paragraphs costs time and labor to the editors. Do not use very thin paper; a sheet of very thin paper may cause extraordinary trouble when mixed with sheets of reasonable thickness. Look at the abstracts in this *Bulletin* to see how the title of the paper and the name of the author are to be arranged, and follow the example. Issues of the *Bulletin* are always appreciably delayed because the editors have to do what the authors should have done.

Remember the rule of the Council that, if an author submits more than one abstract, all but one must go onto the Supplementary Programme. In enforcing this rule, an abstract is credited to the author whose name appears first in the by-line. **By action of our Council, abstracts will not henceforth be withdrawn from our proofs unless the asker sends ten dollars with his request.**

Proceedings of the American Physical Society

Minutes of the 1957 Thanksgiving Meeting at Chicago

Of all of our "traditional" meetings—those which recur year after year at the same time and almost always in the same place—the Thanksgiving meeting is the only one which still invariably envelops us in wholly academic surroundings and so affords us the congenial hospitality of the academic world. In 1956 our host was again the University of Chicago, as for half a century it has been nearly though not quite always (1957 will provide one of the exceptions). Like our other major meetings, the Chicago convention has pretty nearly stabilized in size as measured by number of contributed papers: 175 this year, 183 the previous year, and 168 the year before that. The attendance continues slowly to increase, but not at such rate as to alarm us with the expectation of overtaxing our friendly host: the registration in 1956 was 648. The Division of Solid-State Physics and the Division of Chemical Physics organized symposia, and on the general programme there were invited papers on quite a large variety of topics. The banquet was held in the Quadrangle Club on the Friday evening, with an attendance of 123.

We must not omit to reiterate our warmest thanks to Mrs. Dorothy C. Johnson, able and hard-working Chairman of the Local Committee of this and several past Chicago meetings. She has now announced her withdrawal from this annual task and, much as we regret it, who can blame her? Her successors will have a high standard to match, and we count on her advice to help them approach it.

The Council met on Friday and elected to Fellowship 8 candidates and to Membership 268: their names are printed in this *Bulletin*. The Council awarded to Charles Kittel the 1957 Oliver E. Buckley Solid-State Physics Prize for his work on the applications of magnetic-resonance methods to investigations of the electronic structure of solids. J. W. Beams was nominated to the Governing Board of the American Institute of Physics for a three-year term.

Elected to Fellowship on November 23, 1956: H. W. Bode, C. D. Broyles, T. B. Cook Jr., R. L. Dolecek, C. D. Hause, F. H. Shelton, C. V. Stephenson II, and W. D. Walker.

Elected to Membership on November 23, 1956: Stanley L. Abramson, *Se Hee Ahn, *William Theodore Allen, *Ralph D. Amado, Floyd C. Anderson, *Roger Arawjo, *Donald Arnush, Sabro Asaka, Masao Atoji, *Alvin Herbert Bachman, *James Stutsman Ball, *Brother Ulrick Barnabas, Edward Bernard Barnes, Donatella Baroncini, *David James Bates, Earl C. Beaty, William Martin Becker, Nelson F. Beeler, M. D. Bell, *Aron M. Bernstein, John S. Blakemore, Carl Edward Bleil, *Michael Henry Blue, *Elihu Aaron Boldt, Antonio Borsellino, Stephen Randolph Boyle, Brother T. Brendan, F.S.C., Harold Reid Brewer, George Henry Brigman, Seymour Steven Brody, Stanley Buckser, John Bradley Bulman, *Richard N. Bundy, Duane W. Cady, *Charles A. Caine, D. J. Candlin, *George Emerson Chamberlain, *Fred Chernow, John A. Chiment, *Kenneth M. Clarke, Jack Kent Clifton, John W. Coffman, *Rosemary A. Coldwell-Horsfall, *Paul E. Condon, *Paul J. Convertito, *Victor Cook, Jr., *Ralph Sherman Cooper, Orlie L. Curtis, Jr., *Thomas Bruce Daniel, *Paul C. DeCelles, *Colby W. Dempsey, Herbert H. DerGiragossian, *Robert W. Detenbeck, Jean-Francois Detoeuf, B. Wade O. Dickinson, III, Wadim I. Dobrov, Graydon A. Dodson, Jr., Rodman Elton Doll, George W. Downs, Andrew J. Drummond, *Donald F. DuBois, Madeleine Dubois, *Richard M. Edelstein, *Raymond Ettinger, Helmut Faissner, *John Samuel Faulkner, *Paul Federbush, *C. Rutherford Fischer, Charles A. Flanagan, *Allan Arthur Fleischer, Clyde B. Fulmer, Alexander Ganssen, *John L. Gergen, Charles C. Giamati, Winsten Gin, *Sivert Herth Glarum, *M. Lawrence Glasser, *Walter J. Glowacki, *J. D. Good, *Joel E. Gordon, Ben A. Green, W. D. B. Greening, *Kenneth Randolph Greider, Edward R. Grilly, C. G. Grimes, Gerhart Groetzinger, Janet B. Guernsey, Martin C. Gutzwiller, *Ernest L. Haase, Roy P. Haddock, Herman Paul Haenni, Robert Kingsbury Haling, *John J. Hall, *Laurence Stanford Hall, Francis R. Hama, *William H. Hamum, William W. Happ, *James J. Harmon, *J. Ted Harmon, Henning F. Harmuth, *Michael J. Harrison, Charles Frederick Hartel, Jr., *Stanley G. Hawks, Ray Alden Hefferlin, Milburn Arthur Hehrs, Walter Winfried Heinze, Robert W. Hellwarth, G. M. Henig, Roy J. Heyman, Ursula S. Heyum, *G. Daniel Hickman, Eiji Hirahara, *Melvin G. Holland, Robert Sanchez Hooper, Dale DuBois Hoppes, Leon Horn, Sadao Hoshino, *James S. Hyde, Daniel Hyndman, Takeo Inoue, *Rudolph J. Joenk, Jr., Philip S. Johnson, *Phillips Russell Jones, William Gustav Kaack, Berta Karlik, Alton R. Karoli, David J. Katsanis, H. Douglas Keith, *Joseph Gabriel Kelley, *Richard Pearson Kenan, *R. Glen Kepler, Ray E. Kidder, Hans P. Kleinknecht, Charles H. Klute, Donald Peter Koistinen, Hendrik C. Kramers, *Arnold H. Kritz, *Arlin J. Krueger, *Hans W. Kruger, Hans J. Krusemeyer, *Richard G. Krutchkoff, Aron Kuppermann, *Henry A. Lackner, *Kenneth Eino Lassila, John I. Lauritzen, Jr., Laura Lawrence, *Robert Martin Lea, *Juliette Rose Lee, Robert D. Lerch, *Paul Hersh Levine, *Joseph Lipsig, *Billy Ray Livesay, Paul D. Long, Theodore F. Lyon, Burns Macdonald, III, Jack K. Mackowiak, Richard M. Magee, *Harold Patterson Mahon, Jr., *Dennis Philip Malone, Grant W. Manning, Jr., Richard Eugene Marburger, *Murray J. Martin, *John F. McArdle, *R. K. McCormmack, Daniel F. McDonald, *Thomas Joseph Menne, Ruel Cue Mercure, Jr., Luise Schützmeister Meyer, *Richard Thomas Meyer, *Duane O. Miles, William Edward Mimmack, *Laurence Mittag, Perry Wilkes Morton, Jr., *Francis K. Mullen, *Marshall I. Nathan, Angus Neaves, Jun-ichi Nishizawa, *Milo D. Nordyke, Mirko M. Nussbaum, *Earl Wayne O'Dell, Joseph M. Okada, Susumu Okubo, Harold A. Papazian, *Yoon Soo Park, *Ronald F. Peierls, *Walton A. Perkins, III, *Francis G. Perey, Jay Cee Pigg, Colin Arnold Plint, Philip T. Porter, Alan W. Postlethwaite, Jerome S. Prener, Arnold Prostak, E. Wm. Pugh, Charles W. Querfeld, Warren E. Quinn, Melvin Reier, *Mildred Reif, Lloyd E. Richards, *David Owen Rife, Rudolf Rodenberg, *Ernest Hugh Rogers, *John D. Rogers, Max Tofield Rogers, Mary F. Romig, *David Roper, *William M. Rosenblum, *A. W. Ross, Ronald R. Ross, Richard Ruffine, Porter Raymond Ryason, Chih-Tang Sah, Robert M. St. John, Henry A. Sandmeier, Etsuro Sawaguchi, Karl Scharf, *Kenneth Leonard Schick, *William Carl Schieve, *Keith E. Schmude, John C. Schuder, *James F. Scoggin, Jr., *John Alan Seeger, Rich-

ard Dana Sharp, *Richard K. Sloan, *Arthur C. Smith, Felix T. Smith, *Stanley Fred Smith, *Donald DuWayne Snyder, Evan S. Snyder, David A. Sokolov, Anthony J. Soldano, Jacob Spira, *Thomas Edgar Springer, Jack Steinberg, Melvin Sanford Steinberg, Carl Walter Stempin, *Morton M. Sternheim, *Myron Strongin, H. C. Sullivan, *R. Sun, *David C. Sutton, *Richard R. Szostecki, R. Dean Taylor, Ei Teramoto, Howard Allan Tewes, Otto Helmut Theimer, John W. Thorson, *David J. Thouless, Senzo Tokunaga, James T. Trumbo, *San Fu Tuan, Thomas Charles Tweedie, Jr., Richard Anthony Vagnini, Nancy R. Vinsonhaler, Howard C. Volkin, Yoshihisa Wakuta, *Robert H. Webb, Marcel Wellner, *Carl Werntz, *Nicholas A. Wheeler, *Raymond Morris Wilenzick, Elmer Albert Wolff, Jr., Richard L. Wolfgang, Masami Yamada, Shaul Yatsiv, *Avivi Israel Yavin, *Wolfgang Zernik, and *Jens Christian Zorn.

* Student.

Errata Pertaining to Abstracts C3 and U1 of the 1957 New York Bulletin (Series II, Volume 2, No. 1)

C3, by A. Roberts. In lines 4 and 5, . . . field index $n=\rho/B\cdot aB/a\rho$, or by a variation $R/a -da/dR$ . . . should read . . . field index $n=\rho/B\cdot dB/d\rho$, or by a variation $R/a\cdot da/dR\cdots$.

U1, by Robert T. Smith, Jr., and David Breitenbecher. In the last two lines of the abstract, . . . and appear to be the result of Mg^{24} excitation . . . should read . . . and are the result of Mg^{25} excitation$\cdots$.

Minutes of the 1957 Annual Meeting at New York

THE 1957 Annual Meeting of the American Physical Society, held from Wednesday, January 30, through Saturday, February 2, in the Hotel New Yorker in New York City, proved to everyone's amazement to be *much* the largest meeting that this Society ever held, either by itself or in conjunction (as on this occasion) with the American Association of Physics Teachers. The figure of registration ascended to the stately value of 3110, pressing hard upon the record 3206 set by the joint convention of the American Institute of Physics with ours and all of its other founder societies just one year ago. We shall not attempt to distribute the credit for this huge attendance between our Society and the AAPT. Not by our fault nor by the Institute's, the reservation which we had made for a capacious theater for the Joint Ceremonial Session was voided, and into the Grand Ballroom of the Statler leased at almost the last moment there packed itself a crowd estimated at 2300 to listen to Messrs. Wigner, Zemansky, and Segrè, while many more found themselves forbidden to enter. Even more astonishing was the smash hit scored for the first time in history by the post-deadline session, during which—and on Saturday afternoon to boot—the largest hall normally at our disposal was occupied by so immense a crowd that some of its members did everything but hang from the chandeliers. This was because the blackboards and the grapevine had spread the news that some of the post-deadline papers would be devoted to the issue of nonconservation of parity, which had burst into public view exactly two weeks before. In this same hall the symposium of the Division of Electron Physics and the Buckley lecture had been given before filled seats and quantities of standees. We view with consternation the omen of a rise in the problems of housing the Society to a new order of magnitude. It is somewhat consoling to note that the number of contributed papers did not rise to quite the same extent (376 against 366 last year and 329 the year before).

The banquet of the Society was held in the Terrace Room of the Hotel New Yorker on Friday evening, and at this event, where a great rise in the attendance would have been welcome and well rewarded, we did not have one. The after-dinner speakers were M. J. Kelly who spoke under the title "The work and environment of the physicist yesterday, today, and tomorrow," and R. R. Wilson on "A nuclear physicist's impression of Russia." At this banquet the 1957 Oliver E. Buckley Solid-State Physics Prize was conferred upon Charles Kittel. At this banquet, also, the termination of George Pegram's thirty-eight years of service to the Society in the role of Treasurer was marked by the reading of a testimonial statement prepared by direction of the Council: it appears on page 166 of this *Bulletin*.

The Annual Business Meeting of the American Physical Society was held on Wednesday afternoon at 4:45 in the largest hall which the New Yorker had placed at our disposal: it might as well have been held in the smallest. We have now scheduled the Business Meeting at every time of day from 9 A.M. to 4:45 P.M. at various meetings, and it is evident that all are equally unavailing to bring out a large attendance. The Chairman of the Board of

Tellers announced the votes cast at the election recently concluded for candidates to terms of office commencing at the end of this meeting. Here is the list of those elected: *President,* H. D. Smyth; *Vice-President,* J. W. Beams; *Secretary,* K. K. Darrow; *Treasurer,* S. L. Quimby; *Councillors,* W. Bleakney and W. K. H. Panofsky; *Members of the Board of Editors* assigned to *The Physical Review,* L. L. Foldy, Kenneth Greisen, Thomas Lauritsen, H. W. Lewis of Wisconsin, C. P. Slichter, C. N. Yang; *Members of the Board of Editors* assigned to *Reviews of Modern Physics,* Charles Kittel and G. C. Wick. A run-off election had to be held to determine who should enter the Council, since of the four candidates only one achieved a majority of the total vote. The Society being now in the black, it was not needful to ask those present to approve any increase in the dues.

The Council met on the Tuesday preceding the meeting of the Society. It elected to Fellowship 16 candidates and to Membership 381: their names are printed in this *Bulletin.* W. W. Havens, Jr., was reappointed to the post of Deputy Secretary. To the Nominating Committee (to nominate candidates for terms of office beginning in 1958) it appointed J. H. Van Vleck (*Chairman*), J. L. Fowler, S. A. Goudsmit, Thomas Lauritsen, W. James Lyons, K. G. McKay, J. R. Platt, E. M. Purcell, and R. R. Wilson. To the Committee charged to make recommendations for the 1958 Oliver E. Buckley Solid-State Physics Prize it appointed C. G. Shull (*Chairman*), LeRoy Apker, Charles Kittel, R. J. Maurer, and K. G. McKay.

Taking account of the retirement of George Braxton Pegram from the Treasurership of the Society after thirty-eight years of notable and valued service in that office, the Council authorized the preparation of the testimonial statement which appears on page 166 of this *Bulletin;* conferred upon Dr. Pegram the title of Treasurer Emeritus of the American Physical Society; and made him a complimentary member of the Society, exempt from dues and from subscription charges (the term "honorary member" would have been used but that our Constitution restricts this rank to foreign physicists).

The awarding of thanks for the management of a meeting so great as this one is in itself a comprehensive task. The Chairman of the Local Committee, S. A. Korff, and his colleague and assistant, Arthur Beiser, both of New York University, deserve our warm gratitude for labors of organization such as they had already undertaken more than once. Many undergraduate and graduate students of New York University were serving at the sessions to cope with whatever problems might arise. Immense were the services of the American Institute of Physics and its staff. Our best thanks to all!

Elected to Fellowship on January 29, 1957: R. N. Dexter, D. L. Falkoff, A. T. Forrester, R. H. Kingston, J. D. Knight, Benjamin Lax, I. L. Lebow, J. P. Mize, A. H. Morrish, V. A. Nedzel, R. E. Norberg, Shepard Roberts, P. A. Rodgers, K. R. Symon, R. T. Webber, H. L. Welsh.

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* Student.

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American Institute of Physics

Everyone whose career depends on, or has been helped by, the science of physics is invited to contribute to the Development Fund of the American Institute of Physics. The fund will be used to provide larger working space for the Institute's publishing and other services, to launch an expansion of periodical media for the publication of research reports, and to encourage and improve the study of physics at elementary levels.

It is hoped to raise $150 000 from individuals and $350 000 from industry. Half of the total will be used to convert, for office use, a building on East 45th Street near United Nations Plaza. The building has been acquired with the proceeds of the sale of the old building at 57 East 55th Street. Removal to the new and much larger headquarters is scheduled for June, 1957.

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